OPTIMAL LOCATION FOR A MOBILE BASE STATION IN A COMPLEX NETWORK

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ABSTRACT

The focus of this work is the development of a complete network architecture to enhance telemetry performance using a mobile base station (MBS). The present study proposes a means of enabling both the mobile ad-hoc network (MANET) and a cellular network to operate simultaneously within the same spectrum. In this paper the application of a modified k-means clustering to organize several hundred TAs in a complex network environment is presented. A mobile base station is added to the network to locate the congested area and support the network but positioning itself in the mixed network environment. A scenario with two base stations (one mobile and one stationary) is simulated and results are presented. It is observed that use of an additional mobile base station could greatly increase the quality of communication by providing uniform distribution of node traffic and interference across the clusters in a complex telemetry environment with several hundred TAs.

KEYWORDS

Ad- hoc networks, K-means clustering, Mixed Networks, Spectrum Efficiency, QoS.

INTRODUCTION

Spectrum efficiency is the key challenge in modern telemetry systems. Network telemetry requires moving from a dedicated link structure to a network structure, which is a very complex problem and involves spectrum management tools. This work has focused on providing solutions for two critical needs identified by the Central Test and Evaluation Investment Program (CTEIP). They are: “the need to be able to provide reliable coverage in potentially high capacity environments, even in Over-The-Horizon (OTH) settings” (Cellular Network), and “the need to make more efficient use of spectrum resources through dynamic sharing of said resources, based on instantaneous demand thereof” (Ad hoc Network). Existing telemetry standards employ a radio frequency (RF) link standard, which allows only unidirectional data transfer from a test article (TA) to a ground station over a dedicated channel per TA. This limits the capacity of the system, as resources are not efficiently utilized. Additionally, this standard does not allow data exchange between over the horizon test articles.

In an ongoing effort at Morgan State University (MSU), a new scheme to organize and manage a large telemetry network has been developed. A mixed network structure that employs a combination of cellular and Ad-hoc networks has been previously proposed for networked telemetry. Significant improvements in quality of Service (QoS), and clustering of the complex aeronautical networks have been observed and published in several venues [1] [2] [3] [4]. The proposed technique classifies the test articles into line-of-sight (LOS) and over-the-horizon (OTH) nodes. It then uses an aggregate measure of SNR, traffic, and interference among nodes, to cluster the OTH nodes into clusters that connect with the LOS network through optimal selection of gateway nodes. The results of our clustering algorithm with optimal gateway selection have been published in previous ITC conference [5].

Extra measures need to be taken to guarantee reliable and continuous communication for TAs that are flying in aeronautical channels that have large scale communication paths and sudden changes in the channel topology. Current telemetry technology requires line-of-sight communication between the ground station and the test article [6]. High ground speed of the mobile nodes is also another factor that needs to be accounted for in the network design. The Integrated Network Enhanced Telemetry (iNET) project was proposed in the bid to move to an enhanced network telemetry infrastructure. The iNET project seeks to enhance the current dedicated RF links from the test articles (TAs) to the ground station (GS).The traditional IRIG-106 point-to-point standard is used in aeronautical telemetry application to ensure inter-operability between test articles (TAs) and the ground station (GS) [2], [3]. In our previous work, we implemented a mixed network architecture that illustrated that a cellular-Ad-hoc hybrid network can be used to provide coverage for TAs that are beyond the coverage area of the GS, while maintaining the desired level of QOS for all the TAs in the network. The mixed network uses clustering techniques to partition the aggregate network into clusters or sub-networks based on properties of each TA, which currently include signal strengths, and location [3] [7] [8]. The mixed network management technique is dynamic in all senses and ensures connectivity at any given time. It is shown that, this architecture can be used to provide seamless communication to wireless TAs that are beyond the coverage area of the ground station, while maintaining the desired level of QOS for all TAs in the network [1] [4].

Figure 1 shows a typical aeronautical communication network with several aircrafts scattered around a ground station (GS). Due to high distance and/or obstacles such as mountains between a test article and the ground station, the line-of-sight (LOS) component of the channel might not exist for a number of TAs at all times. In that case, the communication between the over the horizon articles and the GS must be based on reflected paths and other multipath components.

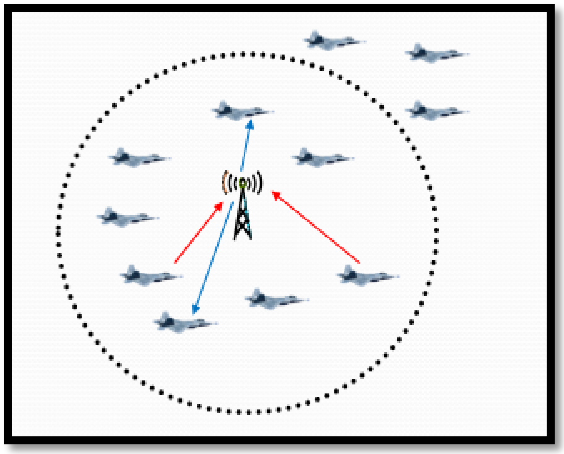

Figure 1: An aeronautical network

Recently, the use of cooperative networking has gained significant grounds for being the ultimate solution to address the over the horizon nodes problem. The proposed mixed network architecture is a realization of cooperative networking technology. In a parallel effort at MSU, the research work on mixed networks is extended to offer a similar network management technique to decongest the cellular network by offloading high bandwidth data users to compatible local area networks (LAN). Early work on 5G cellular technology suggests use of such technique for broadband cellular communication; however 5G standards are far from development.

The main contribution of this paper is the application of a single-stage clustering algorithm to find the optimum location of a mobile base station (MBS) in order to provide the highest average SNR and lowest average delay for all the users. Selection of the optimal location for the MBS that is rotating around the fixed base station is done based on minimizing the same aggregate measure used for clustering the OTH nodes.

MIXED NETWORK

Mixed networking is classifying test articles in the network into two groups i) TAs that can directly communicate with the ground station (cellular nodes) and ii) TAs that are currently or permanently over the horizon (Ad-hoc nodes). After this classification, in the conjunction of the cellular and Ad-hoc regions several gateways are identified to relay the information between neighboring Ad-hoc nodes and the infrastructured network. The trivial benefit of this structure is the expanded coverage area of a ground station to communicate with the over the horizon nodes. While this technique provides a direct or an indirect link to all of the TAs, managing the Ad-hoc nodes and selecting appropriate gateways for seamless communication, are two of the complex problems that need to be solved in order to realize such structure. Figure 2 shows a simplified mixed network environment in which TAs are classified as operating in cellular mode (CM), Ad-hoc mode (AHM) or serving as gateway nodes (GM). The presence of the gateway nodes ensures the connectivity between the cellular and ad-hoc networks.

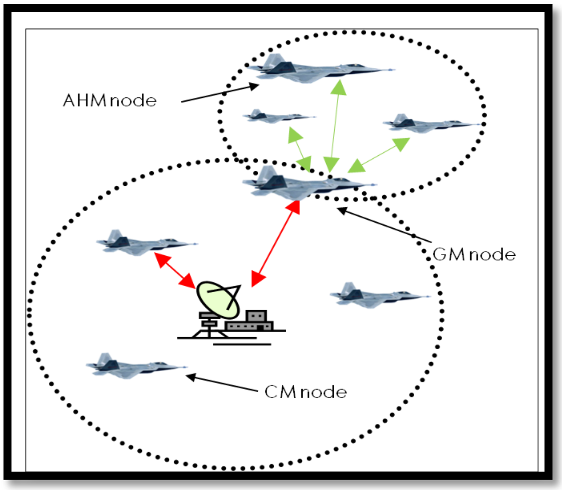

Figure 2: A simple mixed network topology

The Ad-hoc nodes are grouped into several sub networks or "clusters" to enable the routing mechanism to support minimum delay during direct communication with the base station. One of the issues facing the nodes operating in AHM is the shortage of gateway nodes that can be used to relay the information to the BS. Another limitation arises when there is congestion in the ad-hoc network where either the number of TAs or the required bandwidth by the TAs in that ad-hoc cluster is beyond the capacity of a gateway node. We assume that the mixed network is a dynamic network because all of the nodes are mobile. Since gateway nodes play a critical role in the overall operation of the mixed network, we assume that an additional MBS is available in the configuration. The overall performance of this complex network depends on the clustering algorithm that is used to classify TAs to either the cellular network or one of the ad-hoc cluster cells such that the average SNR for all users is maximized while distributing the traffic flow as uniformly as possible.

In our previous work, we used an enhanced K-means clustering algorithm that uses traffic and interference measures in addition to the traditional Euclidean distance measure to assign the Ad-hoc nodes into several clusters cells. Significant improvements in overall QoS and delay of the clustered networks have been reported in [1], [5]. In this work, clustering of the Ad-hoc nodes is performed with two base stations in the network. Figure 3 shows the randomly placed nodes with two base stations. After the enhanced k-means clustering is performed, a gateway is identified for each cluster by testing the average route cost for all the users in that specific cluster. Afterwards, the MBS is rotated around the fixed base station and the overall performance measures of the mixed network are recorded. The optimum location of the MBS is chosen at the end of this circular trajectory. To optimize the location of the moving base station the following cost function is minimized:

$$J(\theta) = \alpha\,\overline{D}(\theta) + (1-\alpha)var(U(\theta))$$

where θ is the angle of the location of the moving base station and $D(\theta)$ is the average distance of users from the gateway. $U(\theta)$ is the number of users in each cluster, and α is the weight control for the measures. Note that if $\alpha = 1$ selecting the θ which minimizes $J(\theta)$ ensures that minimum average SNR is provided for the users. If $\alpha = 0$, selecting the θ which minimizes $J(\theta)$ ensures that traffic is distributed uniformly in the network.

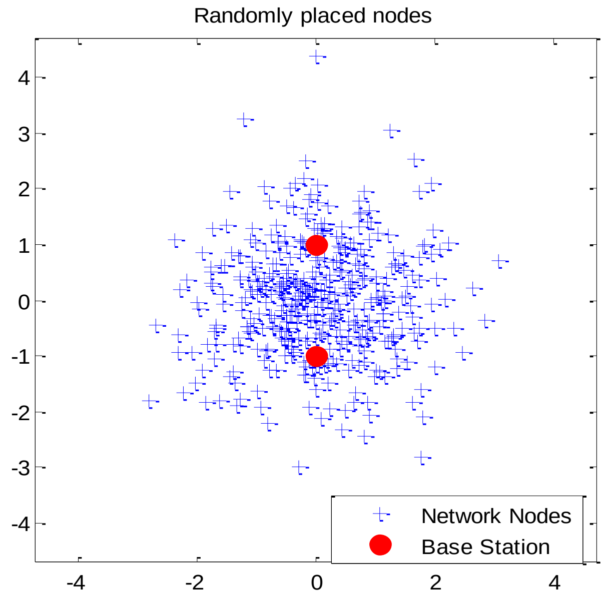

Figure 3: Randomly placed nodes (TAs) with two base stations

Figure 4 shows the trajectory of the MBS around the central BS. To find the optimum location for the MBS, $j(\theta)$ is computed for increments of θ and the angle corresponding to the minimum j cost function selected.

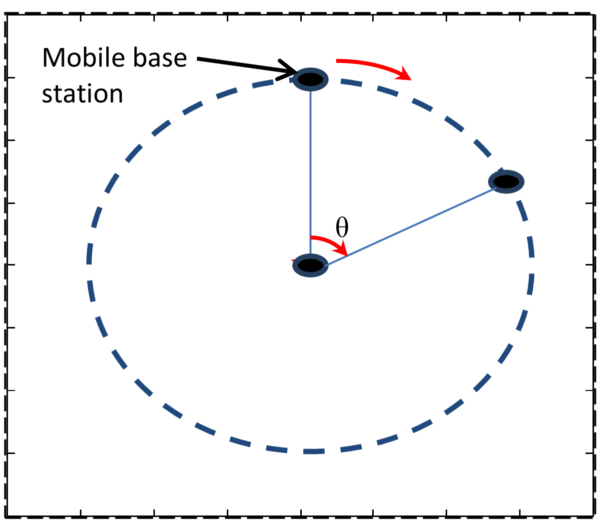

Figure 4: Trajectory of the MBS

Figure 5 shows 8 instances of clustering while the MBS is rotating around the central BS. The MBS is shown with black centered large dot and the static BS is shown by red centered large dot. The clustering is done dynamically in real time. The figure shows two base stations; one fixed (red dot) and one mobile (indicate color). It has 7 cluster cells shown in different colors and their corresponding gateway nodes shown as black dots. As the MBS is rotated around the fixed BS, the ad-hoc cluster cells get re-clustered and their gateway nodes are recomputed based on their corresponding location from both the MBS and fixed BS, while maintaining the optimum traffic distribution in the overall network.

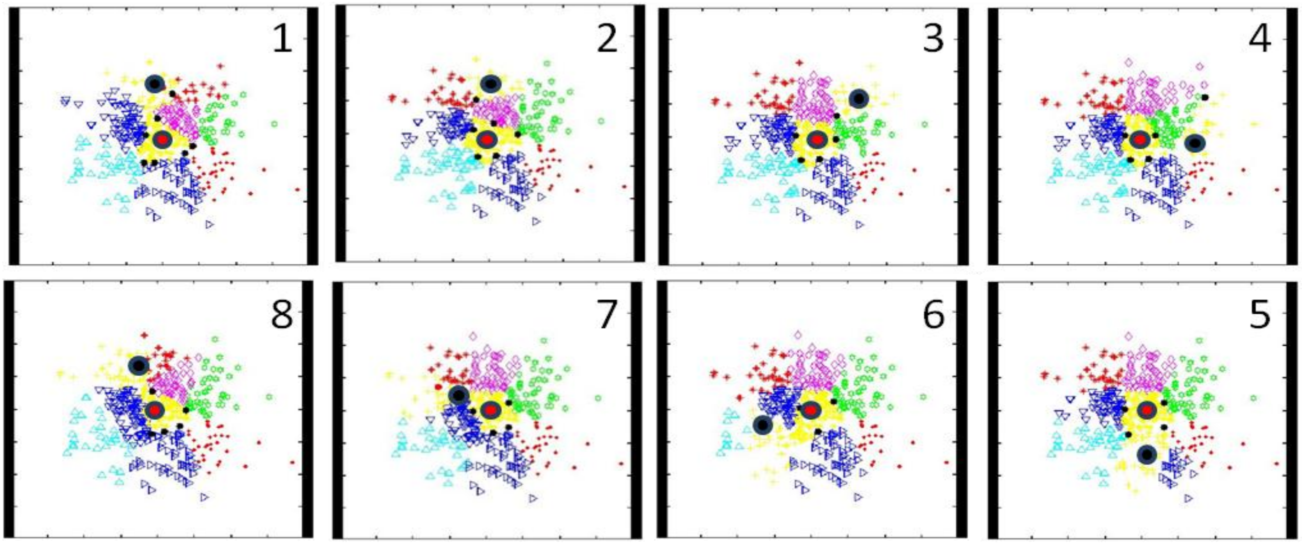

Figure 5: 8 snap shots from clustering of the nodes with a rotating base station

The cost function, j(θ) is shown in figure 6 after completing the trajectory (2π radian for θ). For α=0.8 the minimum of the j(θ) happens at 0.41*2π radian. This is the optimum location for the MBS on the specified trajectory. The radius of the rotation can be varied to find a global minimum for the given cost function.

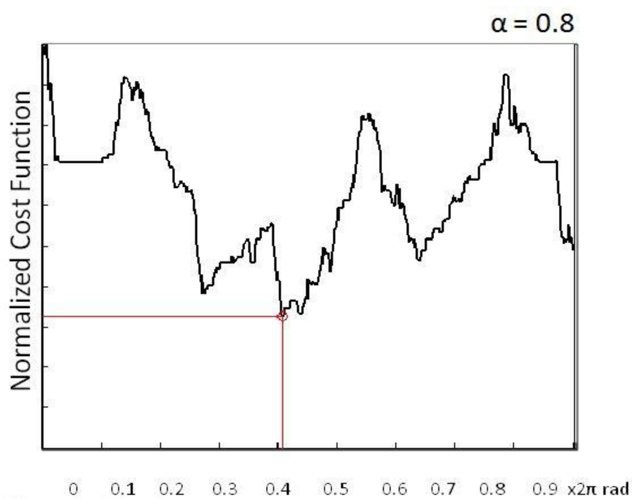

Figure 6: Normalized cost function for the rotating base station

CONCLUSION

In this paper an algorithm for selection of locally optimized location for a moving base station in a complex telemetry environment is discussed. In order to equalize the loads on the ad-hoc clusters in a mixed network environment, a MBS is relocated on a circular trajectory. A cost function to jointly minimize the variance of the number of users in each cluster and maximize the average SNR for all users is defined and the location corresponding to the minimum cost is selected to be locally optimal. For global optimization, the trajectory needs to be expanded and different distances (i.e. different radiuses) from the central BS must be tested. However the possible values for the radius of rotation are limited by the fact that if the MBS if too far out then existence of a gateway node will not be realistic. If the MBS is too close to the central BS, the diversity gain of using two BSs will be compromised. In the future attempts the various radius and different trajectories for the MBS will be analyzed.

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