SYSTEMS APPROACH TO CROSS-LAYER OPTIMIZATION OF A COMPLEX WIRELESS ENVIRONMENT

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ABSTRACT

This paper presents a method for the optimization of mixed networks that incorporates a mixed layer optimization of performance features. The expanded integrated Network Enhanced Telemetry (iNET) system envisioned telemetering for large and complex networks which will require core telemetry networks with ad hoc extensions for coverage. Organizing such a network has been successfully accomplished in simulations using a K- mean clustering algorithm. This paper shows how the features of these network elements will be captured and disseminated in a real system. This management of network elements across multiple layers is characterized as cross-layer optimization. This paper will also show how such cross layer features can be combined for a globally optimum solution. It shows by example how the iNET system comprising multiple ground stations, gateways, frequency, nodes, and three performance measures can be optimized to achieve overall optimal system performance.

KEYWORDS

Cross-layer, Mixed Network, Ad-hoc Network, Cellular Network, Clustering, Nodes preferences

I. PROBLEM DEFINITION

Wireless applications today face demands for more data with less spectrum. Conventional layered solutions work, but these are suboptimal. Because wireless is the weak link in the chain, it is appropriate to breach these boundaries in support of optimized performance. Complex wireless networks manage many issues that affect performance including spectrum, traffic, interference, routing, priority and more. These features are interactive and the decisions and settings at each layer and each node interact with all the others. Optimization can only happen in a centralized function that can dynamically interact with these features to find a setting that is "globally" optimum in some sense. We have used iNET as a worked example of this methodology but it has numerous other applications.

II. INTRODUCTION

To fully optimize wireless broadband networks, both the challenges from the physical medium and the QoS demands from the applications have to be taken into account. Rate, power and coding at the physical layer can be adapted to meet the requirements of the applications given the current channel and network conditions. In the cross-layer approach information has to be shared between different layers of the protocol stack and end-to-end performance is optimized by adapting each layer against this information. Cross-layering is not the simple replacement of a layered architecture, nor is it the simple combination of layered functionality, instead it breaks the boundaries between information abstractions to improve end-to-end performance. The motivation for cross-layering is to improve network performance by violating layered architecture. Cross-layering can improve TCP performance in wireless networks by distinguishing between corruption and congestion, adapting transmission rate, increasing the capacity of the network (resource allocation, FEC, ARQ, HARQ), improving resiliency of the network and to optimizing and adapting mobile applications. A number of proposals for cross layer designs and their corresponding architectures have been published and show how they are getting optimized [11]. The main objective of this paper is to provide a review of cross layering approaches in next generation communications and their differences from existing conventional layered architecture, and how it may be applied to iNET.

111. LAYERING PROTOCOL STACK

All wired and wireless communication systems operate using a set of rules that is known as a protocol stack. Each layer in the protocol stack plays a specific role within the overall communication system. It is very important to first provide an overview of the communication protocol stack, because it gives a comprehensive picture, and helps us better understand how communication networks, both wired and wireless, operate. Figure 1 shows the two most important protocol stacks: the Open Systems Interconnect or OSI model, that consists of seven layers, and the TCP/IP stack with five layers that define communication protocols over the internet. It also shows a sample 802.11 or MANET stack that is based on the TCP/IP. In order to design and implement an integrated wireless LAN-cellular communication system, changes have to be made in the different layers of the TCP/IP protocol stack.

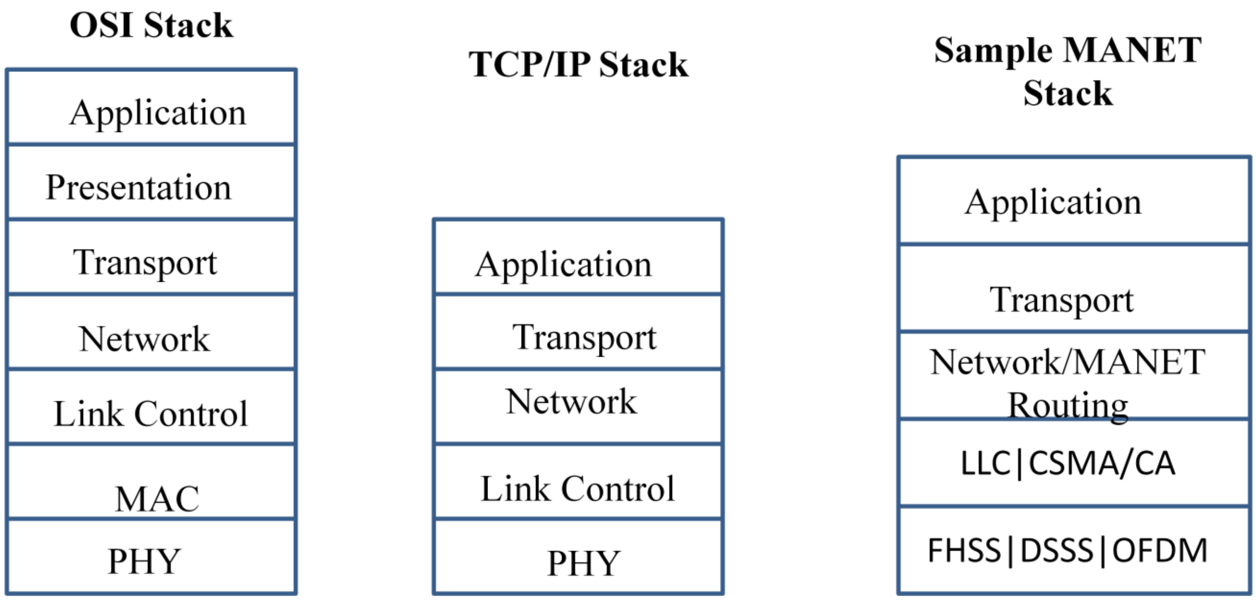

Figure 1: The OSI, the TCP/IP and the 802.11 Protocol Stack

IV. BACKGROUND

The Integrated Network Enhanced Telemetry (iNET) project is based on the development of a complete network architecture to enhance telemetry performance from test articles (TAs) to ground stations (GS). It takes advantage of advances in networking and telemetry technology to satisfy the emerging needs such as higher transmission bandwidth of the Major Range and Test Facility Bases (MRTFB). The iNET program is aimed at adapting cutting-edge network technologies to replace the current point-to-point telemetry system. The new Telemetry Network System (TmNS) will have test articles (TAs), Ground stations (GSs), working together with an interconnected network. QoS data needs to be delivered without delay, or error. Since ad hoc networks are contention based networks meaning the nodes have to compete over a channel in order to send their data to the ground station, Quality of Service management becomes necessary. Research conducted at Morgan State University (MSU) 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).

According to the iNET specifications, connectivity between the TA and GS follows the internet and OSI protocol reference models. Information packets are generated at the highest level of the protocol stack at one end and consumed at the same level of the other end as shown in Figure 2.

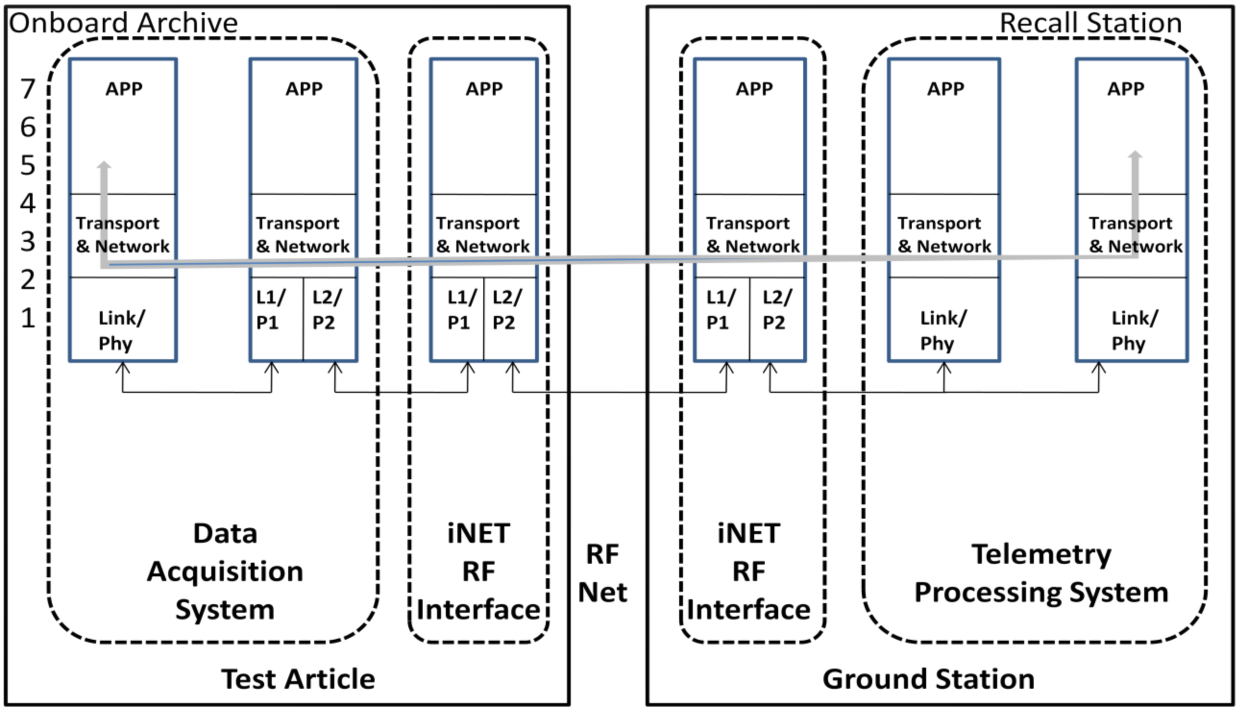

Figure 2: End to End Application Level Connectivity [9.]

The advantages of the protocol layered design are that it divides communication process into simpler and smaller independent components and multi vendor development via standardization. Range interoperability, a key requirement in the standard is the need to have test articles be able to operate at different ranges, with relatively minor changes in configuration parameters and without redevelopment of software or hardware. This has generated a significant motivation for the development of message protocols that govern the interaction between RF network element functional components on the ground and TA [9].

A major disadvantage of protocol layering is performance in the wireless environment (canonical example of TCP performance in wireless medium) and that inter-layer transfers involve non-trivial overhead [12].

Fig 3 establishes the basis of cross-layering between the cellular interface and the ad hoc interface as information is communicated down the stack. Fig 3 shows how telemetry operates using the layered structure in the iNET example and how the preferences (traffic, SNR, interference, QoS) inter-communicate between layers.

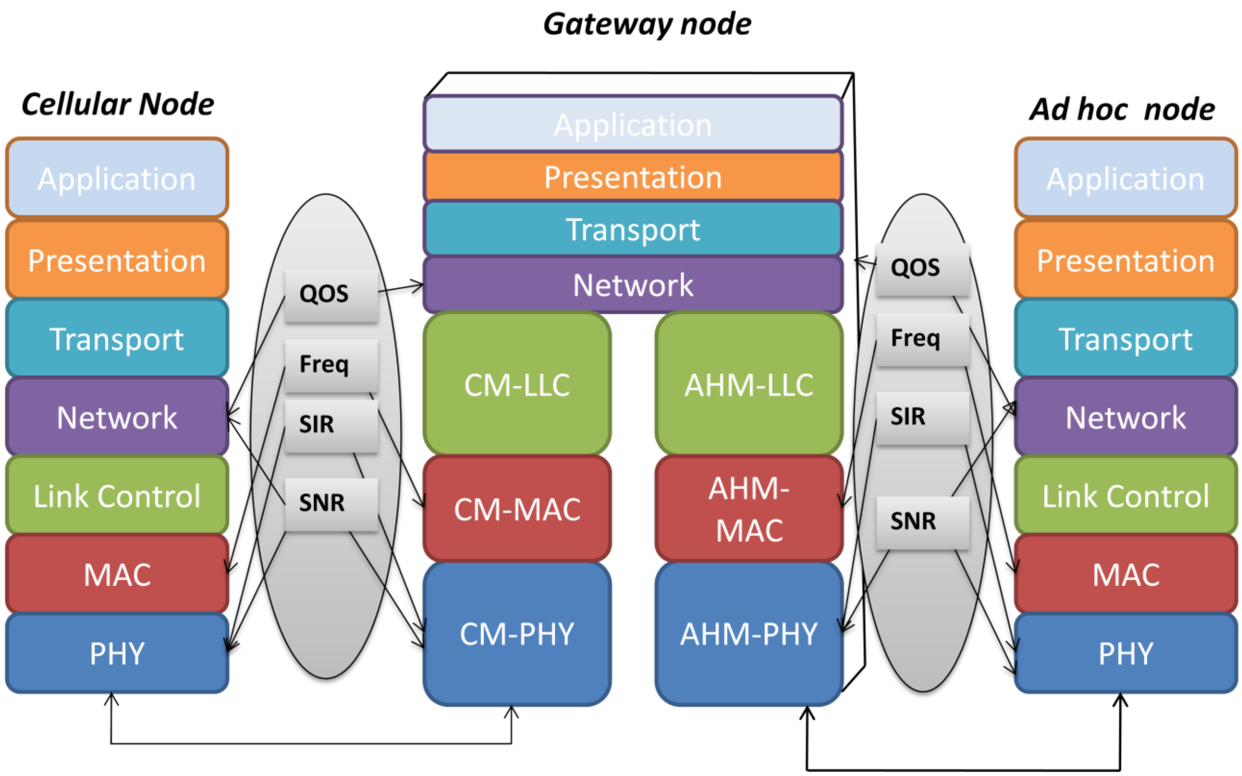

Fig 3. Cross-layering in cellular, Gateway and ad hoc nodes

It is important to see how performance parameters cross layers to increase network performance. Fig4. shows the main functionality of TmNS which is moving data, and the vNET transfers data between end nodes or peripherals on a TA and the rfNET. The gNET that interfaces into the rfNET varies from range to range and thus the TmNS provides interface to the gNET. The rfNET transfers data between the vNET and gNET. In terms of the layering, the physical layer encodes and transmits data bits, the link layer will translate data into frames and add CRC and network layer will do routing and switching functions. One can see how the critical performance features of traffic, SNR, frequency and others cross the layers of the protocol stack.

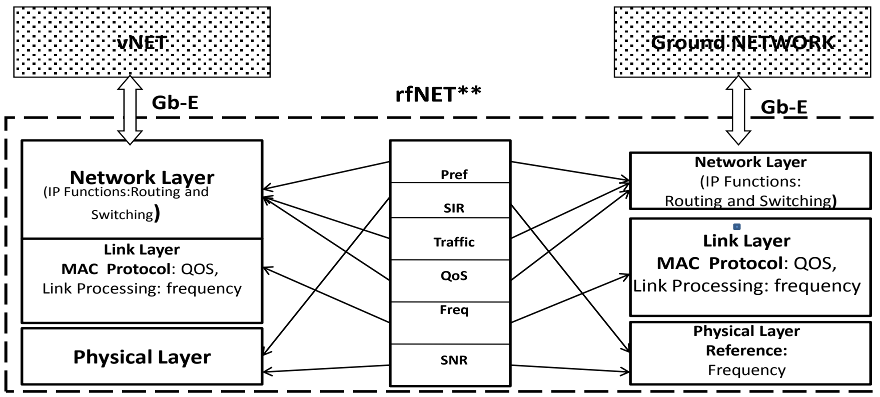

Fig 4.:rfNET layers in OSI Protocol Stack & interfaces[9]

V. LAYERING METHODOLOGY

Cross-layer design and optimization is a new technique which can be used to design and improve the performance in both wired and wireless network users who operate in a time-varying, error-prone network environment. The central idea of cross layer design is to optimize the control and exchange of information over two or more layers to achieve significant performance improvements by exploiting the interactions between various protocol layers. Although wireless networks such as cellular networks, WLANs and MANETs etc are considerably different in terms of their applications and architectures, a common theme in all these networks is the use of wireless channel for communication [7]. Knowing that the broadcast nature of wireless requires elaborate MAC protocols for channel access and that the transmitted signal via the wireless medium is affected by attenuation and degrades more rapidly with distance. In addition, wireless channels are affected by factors like interference, mobility issues and multipath fading etc. All these factors need to be in consideration when designing protocols at different layers of the protocol stack. Hence, designing for wireless networks require more adaptability to avoid a sub-optimal solution and inefficient use of network resources. The overall goal in this new technique of optimizing the performance by cross layer interactions is to improve overall system performance in wireless networks such as increase in network capacity, energy efficiency and QoS [7].

Cross layer design breaks away from the traditional network design where each layer of the protocol stack operates independently. Optimizing one layer a time base on user preferences yields a sub-optimal overall results. Therefore, a cross layer approach seeks to enhance the performance of a system as a whole by jointly managing multiple protocol layers the system benefits from the exchange of information for inter layer actions. This flexibility provides better QoS support given network dynamics and limited resources. For example, the SNR from the physical layer and interference level from the link layer, can be used for the route selection at the network layer and transmission protocol window size adjustment at the transport layer. Another example to illustrate that layering is inefficient when independent can be seen in managing multiple ad hoc networks for mixed networks. Adaptively dividing nodes between ad hoc cluster(A) and ad hoc cluster(B), can creates less traffic, congestion and interference in both B and A. Hence, any preferences (traffic, SNR, SIR, etc) will be suboptimum when each layer is optimized independently. When there is information exchange between layers, there is overall performance enhancement. Performance features are affected as can be seen below. Astatke [10], shows that implementing the multiple distortion measures like traffic distribution, location and SNR, in the enhanced clustering algorithm, performance needs to be coordinated. Another important parameter that affects the performance of the mixed network is the interference power ratio that is generated by TAs from opposite and adjacent clusters on a shared frequency. Traffic management is very important in a mixed network in order to provide QoS guarantees to the different users. Existing cross layer interaction largely focuses on the direct interaction between the protocols by involving only two or three layers and introducing short cuts between protocols and most focus simply on energy constraints and certain forms of security[11].

Why Cross-layering? Its design can play and important role for the next generation wireless systems, featured by all IP-based protocol stack, heterogeneous access networks and multimedia data traffic. Due to lack of information sharing in the OSI & TCP/IP protocol layers, cross-layer designs shifts the research landscape away from optimizing the performance of individual layers and instead treat optimization as a problem for the entire stack.

A number of design proposals have been published. These include designs:- based on architecture violation; creation of new interfaces(upward from lower to higher layer, downward from higher to lower layers, back & forth, iterative flow between two layers), merging of adjacent layers(combine services of two layers-super layer), design coupling without new interfaces, and vertical calibration across layers(adjusting parameters across layers). Some of the open challenges are the interface standardization, coexistence of different cross-layer designs and the role of physical layer. In summary cross-layering increases network performance, adds complexity to system design and should be designed carefully due to additional interactions.

Our preferred method for cross layer optimization is the K-mean algorithm, which is a method of cluster analysis that aims to partition n nodes into k clusters in which each node belongs to the cluster with the nearest mean. This is accomplished by computing their signal to noise ratio (SNR) using their distance from the ground station (GS). In the second stage, it groups the nodes in the ad-hoc network into *k* cluster cells (CCs) based on an Euclidean distance measure by computing the minimum distance between each node and the k-centroids in CC. Although the k-centroids are initially chosen randomly, the algorithm converges when the location of the k-centroids doesn't change anymore indicating that they have reached their optimum position. In this paper, we present an enhanced clustering algorithm as shown in figure 4 below [10]. It can either cluster nodes in the ad-hoc

sub-network by varying the aggregate cluster parameter based on their spatial location only (i.e. AggClusterPar = Euclidean Distance), or it can use multiple distortion measures such as location, traffic and interference to group nodes and set traffic levels in the ad-hoc network such that the number of nodes and traffic level and interference in each CC is optimally distributed among all CCs. Note that these performance features cross the network, link and physical layers shown in fig 4. It should be noted that if the clustering algorithm is based on location only, it might overload one or more CCs with additional nodes based on their locations from the centroid in the

CCs. Also expanding to include both location and traffic [10], yielded interesting simulated Matlab results. To see the effect of the enhanced clustering algorithm, we first organize the nodes in the mixed network using the original clustering algorithm based on spatial location only. Second, we purposely create conditions for congestion in one of the CCs (in this case CC#2) by populating it with additional nodes and creating high traffic conditions. The additional nodes in CC#2 will increase the traffic in CC#2 and also the interference seen at CC#4. We then apply the enhanced clustering algorithm that uses the three distortion measures to optimize the distribution of nodes in the four cluster cells[10]. The results from the simulations of stage 1 and 2 clustering affirms that it can handle it when purposely flooded with additional nodes and the same in re-clustering and reassigning the nodes in different CCs automatically without prior preconditions from the operator[10]. See fig 4a &4b and fig5a&5b[10]

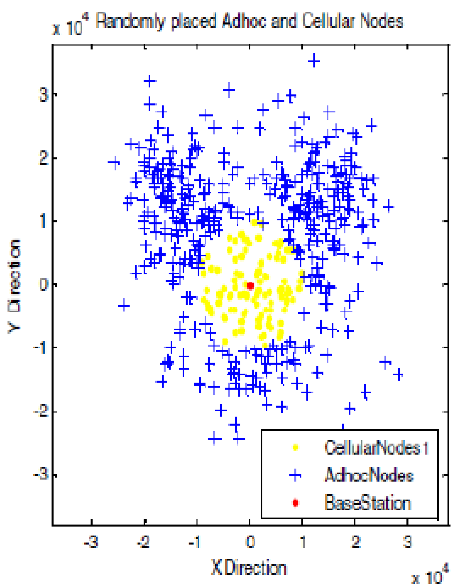

Fig 4a. Stage 1 Clustering of mixed network

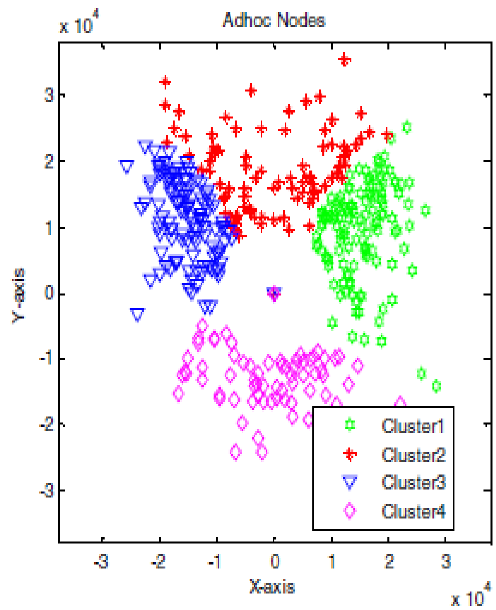

Figure 4b: Enhanced (Stage2) mixed network Clustering

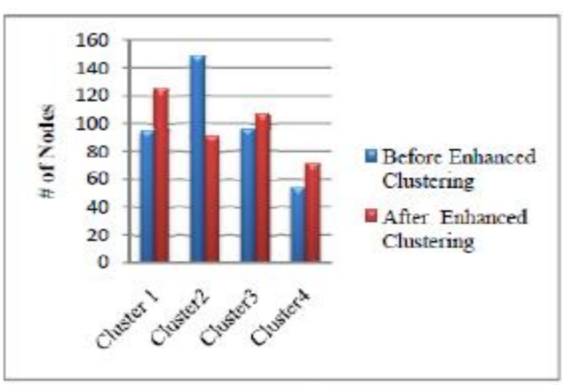

Figure 5a: Node distribution before and after using enhanced Clustering algorithm

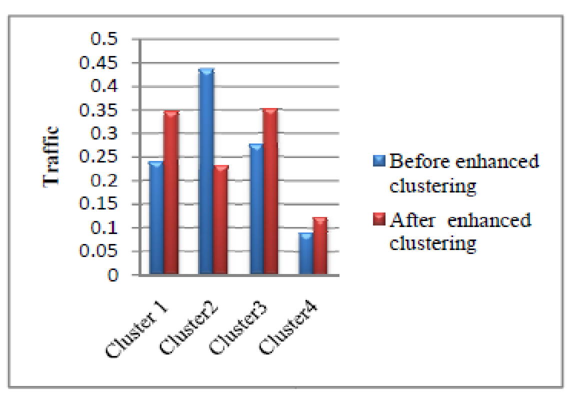

Figure 5b: Traffic distribution before and after using enhanced Clustering algorithm

The main part of our work is the network partitioning algorithm; because the routing and other activities of the network depend on the network partition. The clustering is done at the Ground Station (GS) after gathering data from all the TA's in the network, and it is based on the parameters obtained from the TA's.

The performance shown in Figs 4&5 is illustrative of the benefits of cross-layer optimization. The original layered solution would distribute nodes based only on SNR, a physical layer feature. The cross layer solution however incorporates traffic which is a network layer feature. The K-means algorithm finds the best joint solution which averages out the traffic to avoid congestion while maintaining a manageable SNR.

V1. CONCLUSION AND FUTURE WORK

We introduced the concept of cross-layer optimization for complex wireless solutions and showed how this strategy can be used to enhance performance. The iNET rfNET structure was used as a worked example with Morgan's efforts for mixed networks used to provide the optimization. We successfully adapted the k-means clustering to enhanced k-mean clustering and the distance measure to the Mixed Network to solve iNET's problem of limitations coverage in the cellular network and capacity in the Ad-hoc network. That includes the Ad-hoc users clustering with Multiple Base Stations which helps us to improve routing and mobility management and leads us to the optimization of the hybrid network configuration. We also introduced the multiple distortion measure schemes. This will allow us to re-cluster and optimize the performance of the mixed network for QOS applications based on distance measure or any other performance measures such as traffic intensity, interference and frequency management [10].

V11. ACKNOWLEDGEMENT

The author expresses appreciation for the iNET Program office, SRC, and the TRMC center of DoD for their funding of this effort.

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