A Clustering Approach for MANET Nodes Using Multiple Network Management Criteria

Boris Peltsverger  
Georgia Southwestern State University  
plzcanes@gsw.edu

Svetlana Peltsverger  
University of North Carolina, Asheville  
peltsverger@cs.unca.edu

Michael R. Bartolacci  
Penn State University – Berks  
mb24@psu.edu

Vassiliki Cossiavelou  
Aegean University  
vossiavelou@hotmail.com

Abstract - The authors propose an approach for clustering Mobile Ad Hoc Network (MANET) nodes utilizing a variety of criteria. The clustering approach builds upon the notion of hierarchical or clustered management for MANETs and identifies logical clusters of nodes. A binary relationship matrix between all network nodes is created for each criterion that displays the advantage of having two given nodes in the same logical cluster. The matrices are then combined into a single binary relationship matrix using flexible logic rules that allows a single or multiple criteria to be given priority over others. Finally, clusters are identified in the resulting matrix through a decomposition procedure. Instructions give you basic guidelines for preparing papers for conference proceedings.

I. INTRODUCTION

Mobile Ad Hoc Networks, or MANETs, are a type of wireless network with no fixed infrastructure. The clustering of wireless nodes for various network management purposes has been proposed by several researchers for various purposes in network management. The authors propose a clustering procedure for MANET nodes in order to achieve a range of objectives related to network management.

Most of the previous work in the literature focuses on clustering nodes for routing purposes. Srivastava and Ghosh [11] put forth a unique approach to clustered routing with the creation of two levels of trees with the upper level forming a backbone between the lower layer clusters which also follow a tree structure. These tree structures are formed with a procedure based on the goal of minimizing the number of hops between communicating nodes. Sivavakeesar and Pavlou [10] propose a location-based routing strategy for MANETs in which a region is broken in a matrix of overlapping, adjacent circles or zones where virtual clusters are based on the location of nodes within each zone. This approach looks more strictly at transmission ranges and the nature of links among nodes.

Power management is another criterion used to justify the clustering of MANET nodes. Approaches such as the Intra-cluster Data Dissemination Protocol (ICDP) proposed by Cano and Manzoni [3], [4] look to cluster nodes and use centralized power management for the cluster through the use of a designated cluster-head node. A related approach by Kim, et al. [8] uses “power aware” routing. Again, while such approaches are very useful for power management, they focus on limited aspects of MANET management and do not incorporate multiple factors as allowed by the proposed approach.

Other work related to the clustering of MANET nodes revolves around admission control, resource management, and quality of service aspects of network management. Work by Denko [6], Cardei, et al. [5], and Bononi, et al. [1] focuses on coordination mechanisms and resource management in MANETs which usually include the notion of a “cluster leader” or cluster-head. Unlike the authors’ procedure, all of these approaches are focused on a limited view of MANET management and cannot take into account a range of criteria in a straightforward computational fashion.

Clustering MANET nodes has obvious advantages with respect to overall network management. Ideally, clustered nodes could help with respect to routing in that “local traffic” could be kept local (within a given cluster). This would have the theoretical result of reducing its latency and also providing more capacity across the network for traffic with longer paths in terms of hops. Logical clustering would require the use of a central node that would use knowledge of the overall structure/nature of the network in order to carry out the proposed approach. The implementation of the proposed approach would be useful for military applications where natural clusters of MANET nodes may already exist, but require increased management efficiency. Another advantage of the proposed approach is the ability to “layer” logical clusterings for various network management purposes. Quality of service issues can result in a logical clustering scheme for each type of traffic where a class of traffic is forced to follow certain routes as defined by its associated logical clustering scheme. Again, this may aid in overall traffic management by spreading capacity use across the entire network.

II. OVERVIEW OF MULTI-CRITERIA APPROACH TO CLUSTERING

The authors propose a novel approach for the multi-criteria clustering of MANET nodes. This approach uses logical adjacency matrices derived from the implementation of binary rules based on each network management criterion. For example, a network management concern is the remaining battery power of
network nodes. Nodes with little battery power left pose threats to the overall network connectivity if they are utilized as intermediate nodes in routing traffic or management control functions. All nodes could first be classified using a binary rule where a 1 would be assigned in an adjacency matrix if an existing directional wireless link (based on the transmission range of a given wireless node) between two nodes had a transmitting node with a battery power above some minimum threshold. Otherwise, a zero would result for the link in the adjacency matrix. Other criteria beyond battery power could then be also utilized to generate similar adjacency matrices using similar binary rules. The resulting matrices can then be condensed into a single one using any of a variety of possible network management-guided logic functions. An example of such would be the intersection of all matrices (only elements with 1’s in every matrix would have a 1 in the final condensed matrix for those elements).

Another example might include the logical functions of both union and intersection where the matrices of two criteria are combined using union and then intersected with a matrix that is associated with a third criterion. The logic functions utilized in a given implementation are dependent upon the relative importance placed on each clustering criteria and the nature of each. The proposed approach allows for certain criteria to be given priority over others through the inclusion of OR versus AND logic in the matrix aggregation procedure. The clustering procedure then follows from the single condensed matrix. One of the primary advantages of the proposed approach, the ease of computation through simple logics rules and Boolean arithmetic, is lost if more complex weighting schemes are incorporated into the procedure. This ease of computation allows the approach to deal with nodal mobility through the use of re-clustering. Periodic re-clustering that prevents oscillations in nodal clustering criteria, but still captures the nature of the changing physical locations and states of nodes, is necessary in order to maximize the effectiveness of the proposed approach.

Nodal mobility would present a problem to the proposed approach if periodic re-clustering was not part of the overall implementation of the procedure. The proposed approach can be considered “quasi-static” in nature in that it assumes that nodal mobility has some limit or maximum travel distance per unit time that ensures a given clustering scheme is applicable for some finite time horizon. Early routing schemes for fixed line networks such as ARPANET suffered from oscillations in traffic assignment to paths due to constant regeneration of shortest paths over a very short time window. This sort of behavior in an implementation of the proposed approach can be avoided by accurate estimations of nodal mobility. Accurate estimations of nodal mobility will allow for the time horizon between re-clusterings required to deal with nodal mobility to be timed appropriately to eliminate nodes being swapped constantly between clusters over very short periods of time. The collection of criteria information for clustering, if done on this “quasi-static” basis, also reduces the amount of overall overhead.

A. Generating Clusters from a Consolidated Adjacency Matrix

Once the multi-criteria aspect of the approach has been incorporated into a single matrix, the procedure outlined in this section, based on work by Peltzerger, et al. [9], can be utilized to identify actual clusters of nodes. Based on a matrix \( W \) (single condensed matrix), we can introduce a digraph \( G'' = (V'', E'') \), where \( V'' = (v''_1, v''_2, \ldots, v''_n) \) a set of vertices, \( E'' = (e''_1, e''_2, \ldots, e''_p) \) a set of edges. We assume that all strong components of a graph \( G'' \) belong to one domain. Based on this assumption we can transform graph \( G'' \) to \( G' \) where the vertices of \( G' \) are strong components of \( G'' \). The algorithm of finding strong components of a digraph is well known [7]. As a result of the transformation from \( G'' \) to \( G' \), a partial ordering is introduced on the vertices of \( G' \). The next step of the procedure is to incorporate a linear order into an existing partial order. This can be accomplished through topological sorting [7]. After this step, graph \( G \) results with vertices that are in a linear ordering. Also, the adjacency matrix of \( G \) is a lower (upper) triangle matrix. As a result of transformation from \( G'' \) to \( G' \) on the vertices of \( G' \), the partial order has been introduced. The next step is to include a linear order into an existing partial order. We can reach it by performing topological sorting [7]. After this step, graph \( G \) results with vertices which are in a linear ordering and, consequently, an adjacency matrix of \( G \) is a lower (upper) triangle matrix. Below is the description of an algorithm for creating a quasi-decomposition of the graph \( G \).

Two graphs, \( P \) and \( H \), are isomorphic if there is a one to one correspondence which saves adjacency. If \( A_1 \) and \( A_2 \) are adjacency matrices corresponding to different numerations of the same graph \( G \), then \( A_1 = P^T A_2 P \), where \( P = [p_{ij}]_{n \times n} \), \( p_{ij} = 1 \) if a vertex \( i \) of graph \( G \) became vertex \( j \) of an rearranged isomorphic graph, and \( p_{ij} = 0 \) other wise. The problem can be also formulated this way: decompose a graph \( G \) to nonintersecting graphs \( G_1, G_2 \ldots G_m \) each with a given number of vertices \( |G_1|, |G_2|, \ldots, |G_m| \) and a minimal number of edges among those graphs. Let us introduce square sub-matrices (blocks) \( A_1, A_2 \ldots A_m \) in adjacency matrix \( A \) of graph \( G \) with the given number of vertices \( |G_1|, |G_2|, \ldots, |G_m| \) respectively. This introduction defines a decomposition of graph \( G \) into non-intersecting graphs \( G_1, G_2 \ldots G_m \). Elements \( a_{ij} = 1 \) of matrix \( A \), which do not belong to \( A_1, A_2 \ldots A_m \), correspond to edges which connect sub-graphs \( G_1, G_2 \ldots G_m \). By changing the ordering of rows and columns in matrix \( A \), we will get different decompositions of graph \( G \), because this rearrangement is equal to changing of numeration of vertices in graph \( G \). The resultant graph is defined by matrix \( P \times A \times P \) which will be isomorphic to graph \( G \). In other words, for finding an optimal decomposition of graph \( G \), we have to find the order \( \pi = \pi_1, \pi_2 \ldots \pi_m \) of vertices in which the number of 1’s in diagonal blocks of \( P \times A \times P \) will be minimal, where \( P \) is a matrix of permutations \( \pi \). To find the optimal decomposition, let us transform initial matrix \( A \) into matrix \( A(\pi_0) \) in which nonzero elements are located as...
close as possible to the main diagonal. In other words, we will find the vertices order \( \pi_0 \) of graph G which will have matrix \( \Lambda(\pi_0) = P^{-1} AP \) with minimal value of

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d_i = \max |i - j| \quad \text{for all } a_{ij} \neq 0 \text{ and } j > i
\]

for row \( i \). \( d_i \) is number of columns from column \( i \) till the last column \( j \) containing 1's (upper triangle matrix case). The given solution can be improved, by taking the current solution as initial and generating all cyclic permutations and corresponding transformation of matrix \( \Lambda(\pi(0), (i = 1, 2, ..., m) \). Through this process, we develop a matrix with natural resulting clusters grouped within the resulting matrix.

### III. Exploration of Clustering Criteria

Several aspects of MANET management can be included in the multi-objective optimization modeling approach proposed. Unlike most of the literature which focuses on one or two aspects of network management such as power management or routing efficiency, several goals can be defined in the proposed approach and optimized simultaneously through the clustering of network nodes. The contribution of the proposed procedure is that it presents a framework for including multiple criteria over which to cluster MANET nodes with the opportunity to prioritize various criteria through flexible logic rules.

This section explores a few of these criteria with respect to their usefulness in the proposed approach. Routing efficiency is one possible criterion that can be included in the proposed approach and is a key network management performance measure. Routing efficiency can be defined by several measures including average source-destination delay, average number of hops traversed from source to destination, total number of hops traversed for all traffic, or percentage of traffic that incurs latency beyond an arbitrary threshold. In fact, much of the MANET literature, such as work by Boukerche [2], focuses on the development of efficient routing protocols for MANETs. Routing protocols for MANETs are one of two types: reactive or proactive. Reactive or on-demand routing protocols deal more easily with the changing network topological structure of a MANET, but require speed in their application in order determine routes as needed. Proactive routing where routes are established \textit{a priori} is of little value for MANETs with truly mobile nodes where links are established and broken with great frequency.

The incorporation of routing efficiency into the logical clustering approach may be accomplished through the inclusion and subsequent weighting of criteria. Some examples of possible criteria using the proposed binary logic approach are:

a. length of an edge – if the specific locations of nodes are known with some precision, even in the short run, the physical distance of the wireless link between two given nodes can be associated with routing efficiency in that the closer two nodes are to each other, the greater the theoretical capacity or throughput of that link; a threshold distance can be established for which a 1 is associated with a link of a distance less than the threshold and a 0 for a link greater than or equal to the threshold with the threshold distance being a function of topology or type of nodes involved

b. degree of a node – theoretically, a node with many links emanating from it is most likely a node on many paths throughout the network and a key node with respect to routing in that part of the network; it is desirable from a routing point of view to have a node with a large degree in each cluster, thus decreasing the number of hops for traffic within a cluster and possibly between clusters; a method for encouraging this is to assign a 1 between nodes that have a link where one of the two is a node of low degree and the other is a node of a higher degree, or a 0 otherwise

c. number of hops along the shortest path to another node – this criteria attempts to reduce the queueing delays associated with traversing multiple nodes between sources and destinations of traffic; a 1 could be assigned between two nodes if the number of hops between them is shorter than some given threshold number and a 0 otherwise; this criteria ideally produces clusters of nodes that are logically in the same vicinity (ignoring the physical distances of links)

Another possible criterion for clustering in the proposed approach is the remaining battery power of nodes. As previously mentioned, battery power is a key parameter with respect to network management and connectivity. If a node’s battery is low, it is prone to failure or has severely limited transmission capabilities. Nodes with low batteries should not be considered for key functions in network management. A possible implementation of this criterion within the proposed approach is the establishment of a minimum threshold for power for nodes and the assignment of a 1 or 0 based on a given node’s remaining power and its comparison to this threshold. This would effectively eliminate certain nodes from consideration in the logical clustering scheme. If one of the goals of clustering were to ensure routing paths with some temporal stability, the elimination of nodes with lower power for “backbone” routes would be advantageous. Thus nodes which did not meet this criterion would not ultimately wind up as part of a cluster, but could be simply treated as if they were a cluster themselves.

A host of other possible network management criteria exist that can be incorporated into the proposed approach. The ease of computation and its ability to handle multiple criteria make it both flexible and easily implemented within a protocol. The dynamic nature of the topology of MANETs would require periodic re-clustering in order to reap the benefits of the proposed approach over time. The notion of re-clustering may simply involve the adding of a new node to a cluster (when a previously disabled node is enabled or a new node moves into the network coverage area) or the re-clustering of the entire network. The use of logic rules for dealing with the gain of network nodes can still apply for a partial re-clustering.

### IV. Summary
The authors propose a multi-criteria approach for the logical clustering of MANET nodes. The approach involves the representation of nodes as binary variables in matrices for each criterion. These matrices are then aggregated into a single matrix using logic rules and an algorithm is performed that defines the logical clusters. The proposed approach is noteworthy in that it is simple to execute and allows for multiple “layers” of logical clustering for a single MANET.

REFERENCES


