CLUSTERING ALGORITHM FOR MULTI-RADIO WIRELESS MESH NETWORKS

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ABSTRACT

Clustering methodology is a topology control approach being used in wireless sensor networks to improve scalability and prolong network lifetime. Similarly, in ad hoc networks, clustering is being employed to provide semi-management functionalities and capacity enhancement. A clustering topology control technique can also be designed for multi-radio wireless mesh network. This would utilize the advantage of the multi-radio implementation in the network. The aggregation of these two would result to a more stable, connected, scalable, heterogeneous and energy-efficient network. On this paper, we design a clustering approach for multi-radio wireless mesh network that would utilize these advantages.

Keywords: multi-radio, wireless mesh networks, clustering

1. INTRODUCTION

A mesh network could be applied to a number of known systems. It could be a system of wireless sensors interconnected via mesh. Wireless Mesh Network (WMN) is composed of mesh routers and mesh clients. Mesh routers are the gateways/bridge and router of the network. On the other hand, mesh clients can be simpler than mesh routers in design but they could also still route packets. Mesh routers form the backbone and are essentially not mobile. Moreover, they do not have strict constraints on power consumption compared to mesh clients. Mesh clients are highly mobile and are likely to be battery powered. Figure 1 shows a wireless mesh network that is comprised of both wireless mesh routers and clients.

Although, it has been shown that WMN has a number of advantages over other technology [1], it could be further enhanced by introduction of multi-radio components. A multi-radio system can be employed in a mesh network and this feature can be a facility to provide better energy management and improve capacity. Furthermore, this can be used as a general solution to handle mobility management. As we consider the presence of one or more radios in the same device, we would try to address solutions to common single-radio wireless problems. The advantages of multi-radio will be presented and how they can be used to enhance wireless mesh network will be described. We present a couple of things to consider in a multi-radio system that can be utilized for wireless mesh network.

The rest of the paper is organized as follows. Section 2 presents related works. Section 3 describes the clustering topology control protocol. Section 4 presents the performance analysis. Finally, Section 5 concludes the paper.

2. RELATED WORKS

The definition of topology control has evolved as researches

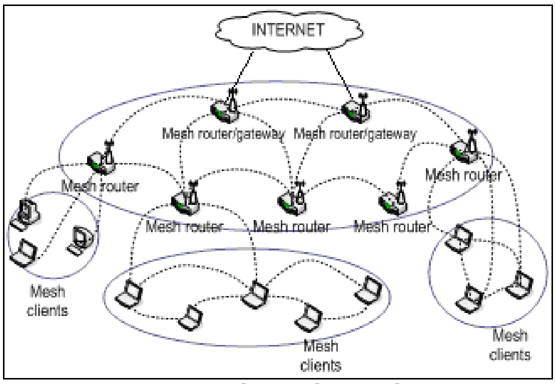

Fig.1 Wireless Mesh Network

proliferate to seek the most appropriate method. The foregoing goal of topology control is to provide an energy efficient network and it eventually grew as more protocols were developed. The nascence of topology control can be rooted from schemes that limit the number of neighbors of a node by controlling transmission power control or reducing the transmit radius [2], [3], [4] and [5] are some of the studies that discuss various ways to do transmit power adjustment. Prior to clustering, the most popular topology control protocols then were schemes that determine a set of connected representative nodes. GAF [6], Span [7], ASCENT [8] belong in this category. In GAF (Geographic Adaptive Fidelity), the network is divided into grids and designates one node as the representative for each grid cell. While in Span, certain nodes are assumed to a role of a coordinator based on connectivity criteria while other nodes are allowed to sleep and not to participate in routing. Similarly, ASCENT (Adaptive Self-Configuring sEnsor Networks Topologies) chooses which nodes are active for a given time with consideration of both connectivity and communication reliability. The emergence of clustering methods can be traced back with the introduction of two distributed algorithms: lowest-ID algorithm and highest connectivity algorithm which are discussed in detail in [9]. In these two algorithms, a clusterhead is chosen among certain group of nodes. As their name suggest, the former algorithm selects the node with the lowest ID while the latter selects the node with the highest connectivity. Although, originally, clustering have been developed for wireless ad hoc networks to provide a kind of infrastructure that would allocate resources and support multi-hop routing. Its energy efficiency potential has also been examined by applying it to wireless sensor networks. One of the first clustering protocol is LEACH (Low Energy Adaptive Clustering Hierarchy) [10] which is based on one-hop communication which transmits aggregated data of nodes from clusterhead to base station. Another one is

HEED [11] “Hybrid, Energy-Efficient, Distributed”, which is unlike LEACH, uses multi-hop communication and selects clusterhead in O(1) time. Similarly, EECS [12] “Energy Efficient Clustering Scheme” performs clustering by electing clusterhead with the most residual energy.

In [1], a detailed survey or wireless mesh network is presented. Some open issues regarding wireless mesh networks and detailed analysis on WMN-specific problems are mentioned. It is known that multi-radio implementation of WMN would greatly increase the capacity of the network. Multi-radio wireless systems have been considered to be the solution for common wireless problems like energy management, capacity enhancement and mobility management [13]. The researchers have shown that implementing both high power radio and low power radio on a device and altering its operation to run on low power radio during wake up phase and sending control messages improve power savings. They also showed that if a device can be tuned to hear different interfering channels with proper channel assignment and protocol, the capacity allocation can be greatly improved. Lastly, the delays created by handover can be minimized as nodes can associate to another access point, AP before it could disassociate with an old access point. Clustering is a method of dividing the network into clusters. It is architecture that can be applied to multi-radio wireless sensor network taking into account both heterogeneity and mobility [14]. A mobility-based clustering as [15] is proven to be adaptive and stable in ad hoc networks. Clusters are often employed to impose a hierarchical structure for scalability and spatial reuse. Clustering applied to multi-radio ad hoc network [16] is found to be also effective in capacity optimization when the clusters are of equal size.

There are several clustering algorithms, and an example is in [17]. In this method, they have presented a fully distributed multi-radio backbone synthesis algorithm which contributes an important feature of clustering methodology, that is, construction time is bounded by a constant time, independent of the number of nodes. Unlike most clustering algorithms that limit a one-hop cluster, [18] upper bounding the number of hops a node can be from its clusterhead, which the authors have shown, is fairer and more stable. Factors like how mobility affects cluster formation and how many nodes should form a cluster should be the basis for decision making. It is important however, that before any algorithm are to be introduced, a based model and efficiency should take into consideration. [19] has revisited mobility models that can be employed to ad hoc networks and [20] has shown how to compute time complexity in some well known clustering algorithm. The theories to be introduced on this paper are formulated with the guidance of the related literatures presented in this section.

3. PROPOSED MODEL

A. Multi-radio Wireless Mesh Network System

The system to be described all throughout this paper is comprised of nodes in wireless mesh network environment, wherein the nodes belong into two categories: a mesh router or a mesh client.

The following are assumptions for wireless mesh routers:

- Mesh routers are not mobile
- Mesh routers are evenly distributed in the system
- Mesh routers are mains powered
- Mesh routers are equipped with two radios
  - Low power radio
  - High power radio

For wireless mesh clients:

- Mesh clients are mobile
- Some mesh clients move in a groups
- A node can have individual movement
- Mesh clients are battery powered
  - Low power radio

Both node entities do not have GPS (global positioning system) in them; therefore, the following assumption is helpful:

- Nodes are deployed in a static channel. It means that signal fading and multi-path effects are not considered.

B. Mobility Pattern

As described earlier, WMN is composed of different entities interworking to form a dynamic system. The reason why we need to consider mobility is to account for the nature of wireless mesh network and test our proposed algorithm for stability.

The choice of mobility pattern in WMN should take into account the heterogeneity of the network. WMN is composed of different type of nodes. These differences between the network nodes should dictate the mobility pattern to be used in the system.

For this purpose, we would like to use the Mobility Vector Model [21]. The mobility of the node is expressed by (1).

$$\vec{M} = \vec{B} + \alpha \vec{V} \tag{1}$$

Where:

$\vec{M}$ - mobility vector (x_m, y_m) or (r_m, Θ_m)

$\vec{B}$ - base vector (b_m, b_m) or (r_m, Θ_m)

$\vec{V}$ - deviation vector (v_m, v_m) or (r_m, Θ_m)

α - acceleration factor

Base Vector defines the major direction and speed of a node. A Deviation Vector stores the mobility deviation from the base vector. The α provides smooth speed transition in the mobility metric. The mobility vector described in (1) would only apply to wireless mesh clients since wireless mesh routers are not mobile. The group mobility can be represented by defining the base vector as the group movement while the deviation vector represents the individual movements.

C. The Algorithm

The clustering topology control algorithm is divided into 2 phases. First is the formation mesh backbone and the other phase is clustering. A node is a neighbor of another node if they are within the transmission range from each other.

1. Phase 1: Formation of Mesh Backbone

The formation of mesh backbone is initiated by the mesh routers via their high-powered radios. Since wireless mesh router are essentially immobile and mains powered. This phase shall be done at one time only.

The algorithm will start with routers sending *Hello_1* messages to all neighbors. In case of a tie, a weight factor is introduced. Weight could be ID or any stability measure. Fig.2 shows the algorithm for mesh backbone formation. P_R is defined as received power.

2. Phase 2: Clustering

The wireless mesh nodes will form a group according to their mobility pattern. Therefore, from (1), nodes with similar base vectors are in the same group and have links to each other. The clustering algorithm starts with wireless mesh routers. The wireless mesh routers will disseminate *Hello_2* messages using their low-powered radio to wireless mesh clients. If another wireless mesh router received this type of hello message, it will only ignore and discard the message. The pseudocode in Fig. 3 shows how this phase is done. The hello message on this phase contains weight information as well.

After this phase, clusters are formed with mesh routers as clusterhead and mesh clients as cluster nodes.

3. Maintenance

Since wireless mesh routers are more powerful in terms of hardware than wireless mesh clients then it would be smart to add a kind of maintenance scheme in them. Mesh routers should poll their respective cluster nodes if they are still reachable. This is a trivial mechanism and can be implemented in a number of ways.

4. PERFORMANCE ANALYSIS

Since, Phase 1 and Phase 2 are being executed using different radios; these two phases can be done simultaneously. This saves time and initial start ups in the network. The messages are sent via different radios and this reduces traffic. Overhead is not a problem since hello messages always come from mesh routers. Capacity is utilized efficiently since one mesh router is assigned to one cluster. Also, since P_R and mobility is taken into account, stability is guaranteed.

In this section, we try to analyze the performance of the algorithm by proving some claims.

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Lemma 1: All wireless mesh routers are interconnected at the end of Phase 1.

Proof: Since the nodes are uniformly distributed throughout the network, a mesh router would surely be associated at the end of Phase 1. Given a mesh router on a space $G(R)$ of arbitrary size s, there exists another mesh router R_1 within a transmission range T_R in a uniformly distributed space, such that a mesh router has at least one neighbor R_n that exist and one *hello_1* message received which can be a candidate for association.

Lemma 2: There exists at most one mesh router in the vicinity of another for mesh router that can be associated.

Proof: We could denote R as the set of all mesh routers and R' is the set of mesh routers that have the highest P_R or highest weight within its T_R where $\forall R_n \in R'$, $R_n'' = \{R_x | d(R_x,R_n) \leq T_R, R_x \in R\}$. We also define $R_x \in R_n''$ belongs to R' which is a contradiction of the Lemma. Based on the algorithm, $R_n.P_R > R_y.P_R$, $\forall R_y \in R_n''$. Since $R_x \in R_n''$, then $R_n.P_R > R_x.P_R$. If R_x belongs to R', then $R_x.P_R > R_y.P_R$ which is a contradiction. Therefore, if $R_n \in R'$ and $R_x \in R_n''$, the statement $R_x \in R'$ is false.

Lemma 3: A wireless mesh router could send a maximum of k number of *hello_1* messages. Thus, the control overhead complexity is of constant order of O(1) per node.

Proof: The length of each hello messages is fixed length. The information, like ID and other stability measure in mesh routers are kept unchanged. Also, since the mesh routers do not move along the space G, it is always have a maximum of k neighbors at a given time. Obviously, there is no need for another run of Phase 1 since at the end of the procedure, all mesh routers are associated, thus giving the algorithm to end at a definite time.

```
Procedure PHASE_1{
  For each wireless mesh router
  {  Status = Not Associated;
     Send Hello_1 msg to each neighbors;

     For each Hello_1 msg received{
     {
        If (PR from a neighbor is the highest for all){
           Status = Associated /*using high-powered radio*/
        }
        Else {
           Status = Not associated
        }
     }

     If Status = Not associated{
        For each Hello_1 msg received{
        {
           If (Weight from a neighbor is highest for all){
              Status = Associated /*using high-powered radio*/
           }
           Else {
              Status = Not associated
           }
        }

     If status = Not associated {
        Establish link to the nearest mesh router with status = associated
        Status = associated
     }
  }
}
```

Fig. 2 Phase 1: Formation of mesh backbone

```
Procedure PHASE_2(test){
  If (test = PR){
     For each Hello_2 msg received
     {
        If (PR from a neighbor is the highest for all){
           Status = Associated /*using low-powered radio*/
        }
        Else {
           Status = Not associated
        }
     }
  }
  If (test = weight){
     For each Hello_2 msg received{
     {
        If (Weight from a neighbor is highest for all){
           Status = Associated  /*using low-powered radio*/
        }
        Else {
           Status = Not associated
        }
     }
  }

  If Status = Not associated and test = PR{
     Call Procedure PHASE_2(weight)
  }
}
```

Fig. 3 Phase 2: Clustering

Lemma 4: A group of wireless mesh clients will be associated by the end of Phase 2.

Proof: Since, one of our assumptions is that wireless mesh routers are uniformly distributed about G, therefore, on any point G_{xy} space there is an equal probability that a mesh router is present. Thus, a group of mesh client will receive at least one *hello_2* message from a mesh router.

Lemma 5: It takes one run of procedure Phase 2 to form initial clustering.

Proof: Because of Lemma 3, this is a trivial case of a time definite algorithm. Repeated calls to Phase 2 depend on the implementer and the mobility of the system (α, [B, V] vectors). Thus, the time complexity of the algorithm in Phase 2 is upper-bounded by a constant value such as a mobility factor.

Lemma 6: The whole algorithm is upper-bounded by a definite time $max\{t_1, t_2\}$.

Proof: Both Phase 1 and Phase 2 do not go into infinite loop and finish at a definite time t as proven by *Lemma 1* and *Lemma 5*. Moreover, the two algorithms can be done at the same time because of multi-radio advantage of mesh routers, hence, making total time, t smaller. Let say, that Phase 1 would be finished at time, t_1 and Phase 2 at time, t_2, therefore if the two algorithms will be executed at different times, the total time for it to finish would be $t_1 + t_2$. On the other hand, when the two algorithms will be executed at the same time because of multi-radio approach, it is bounded by the slower algorithm, which is $max\{t_1, t_2\}$. It is easy to see that, $t_1 + t_2 > max\{t_1, t_2\}$.

5. CONCLUSION

This paper presents a clustering algorithm for multi-radio wireless mesh network. The introduction of multi-radio in the network is fully utilized to bring out its advantages for this kind of network. Clustering in multi-radio environment is proven to be effective in prolonging lifetime and stability of the network,

For our future work, we would like to extend and analyze our work from non-uniform node distribution system.

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