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# A node quality based clustering algorithm in wireless mobile Ad Hoc networks

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**Abstract**

A new strategy for clustering a wireless AD HOC network is proposed. The main contribution of our work is to improve Weighted Clustering Algorithm (WCA) [5] and other similar algorithms. In literature, the node degree is considered as an important weight metric in clusterhead selection process. Unfortunately, this metric is not consistent especially when it is considered separately at the node environment such as the neighbours' location within the transmission range zone of this node. To overcome this inefficiency, we propose two new models. Thereafter, we combined these two models to take profit of their efficiencies. The new combined model, motivates us to generate and reformulate many node degree based formula given in literature and dealing with Quality of Clustering (*QoS*) as stability and load balancing clustering parameters. We showed that our algorithm outperforms WCA in the in terms of cluster formation and stability.


*Keywords:* ad hoc networks, clusters; load balancing; stability;

## 1. Introduction

Wireless ad hoc networks are multi-hop, self-organizing autonomous networks, composed of some mobile terminals including radio receivers and transmitters [1]. Wireless ad hoc networks do not rely on any existing or predefined network infrastructure, and terminal nodes randomly dispose [1]. Nodes within transmission range can communicate directly with each other. Nodes outside the transmission range must communicate indirectly using a

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multihop routing protocol. Individual nodes are responsible for dynamically discovering the route. Instead many clustering schemes have been proposed to organize the MANET into a hierarchy with a view to improve the efficiency of routing [2]. Clustering means a way to reconfigure all nodes into small virtual groups according to their regional vicinity and is defined as Cluster Head (CH) and cluster members that are determined with the same rule. Every clustering algorithm consists of two mechanisms: cluster formation and cluster maintenance [2].

In [2], the authors have proposed a combined weight clustering algorithm to establish a stable clustering architecture. The proposed algorithm has a hierarchical structure that can maintain the topology of MANET as stable as possible, thereby optimizing network performance and making efficient resource allocation for nodes. This makes it possible to maintain efficient and stable topology in MANET environment. In our algorithm, the node with the highest fitness is elected as the CH. In the proposed algorithm, due to the weight group, cluster creation is done very quickly which causes network services to be more accessible.

In [3], the authors proposed a sservice discovery architecture based on clustering in the Cluster-Based Service Discovery Protocol for Mobile Ad-hoc Networks. It performs the CH selection by allotting a combined weight value based on the factors power level, connectivity and stability, intended for wireless mobile ad hoc networks. The proposed method permits the switch over of service discovery messages only among the cluster members. It also considers the capabilities of the nodes for the distribution of workload.

In [4], the authors introduced a new type of algorithm called Enhancement on Weighted Clustering Algorithm [EWCA] to improve the load balancing, and the stability in the MANET. The CH is selected efficiently based on these factors like high transmission power, transmission range, distance mobility, battery power and energy. Since the CH will not be changed dynamically, the average number of cluster formations will be reduced.

A weight based distributed clustering algorithm (WCA) which can dynamically adapt itself with the ever changing topology of ad hoc networks is proposed in [5]. In this approach, the number of nodes is restricted to be catered by a CH, so that it does not degrade the MAC functioning. It also has the flexibility of assigning different weights and takes into account a combined effect of the ideal degree, transmission power, mobility and battery power of the nodes.

In [5], we observed that all nodes have the same chance to participate in the CH selection process, which affects the quality of the formed clusters. The motivation for the present work is to prioritize only some favorable nodes in this process. Consequently, we introduce our models to overcome the previous inefficiencies.

In the remainder of this paper, Section 2 presents problem specifications. Our algorithm models are given in Section 3. Section 4 illustrates clustering quality. The formal definition of our algorithm and its illustrative example are provided in Section 5. Conclusions are given in Section 6

## 2. Network model and problem specifications

As defined in [5], the network formed by the nodes and the links can be represented by an undirected graph $G = (V, E)$, where $V$ represents the set of nodes $v_i$ and $E$ represents the set of links $e_i$. Note that the cardinality of $V$ ($|V|$) remains the same but $|E|$ always changes with the creation and deletion of links. Clustering can be thought of as a graph partitioning problem with some added constraints. As the underlying graph does not show any regular structure, partitioning the graph optimally (i.e., with minimum number of partitions) with respect to certain parameters becomes an NP-hard problem [6]. The neighborhood $\Gamma(v_i)$ of a CH $v_i$ is the set of nodes which are directly linked to it and which are in fact the nodes lying within its transmission range ($R_{v_i}$). This defines the degree of the node $\boldsymbol{v_i}$:

$$\Gamma(v_i) = \{v_j,\ such\ that\ \ dist(v_i, v_j) < R_{v_i}\} \tag{1}$$

where $dist(v_i, v_j)$ is the measured average distance between $v_i$ and $v_j$. Similar to [5], when a system is initially brought up, every node broadcasts its id which is registered by all other nodes lying within *its* transmission range. It is assumed that a node receiving a broadcast from another node can estimate their mutual distance by measuring the ratio of receiving power and transmission power. The node degree of a node $v_i$ is deduced as the cardinality of the set $\Gamma(v_i)$:

$$deg(v_i) = |\Gamma(v_i)| \tag{2}$$

More formally, we are looking for the set of vertices $S \subseteq V(G)$, such that the union of $\Gamma(v_i)$, where $v_i \in S$, forms $V(G)$. The set $S$ is called a *dominating set* such that every vertex of $G$ belongs to $S$ or has a neighbor in $S$. To meet the requirements imposed by the wireless mobile nature, a clustering algorithm is required to partition the nodes of the network so that the following ad hoc clustering properties are satisfied [7]: (a) Every ordinary node has at least one CH as neighbor; (b) Every ordinary node affiliates with the neighboring CH that has the smaller weight; and (c) no two CHs can be neighbors. Next, we propose models for our algorithm.

## 3. NQCA models

In our NQCA (*Node Quality based Clustered Algorithm*), we propose two new models in clustering algorithms: node priority and range zone aggregation models.

### 3.1. Node priority aggregation model

We observe that in [4, 5, 8, 9, 10], border and isolated nodes can be selected as CHs. Fig. 1(e) depicts the cluster formation stage provided in [5] as a result of WCA algorithm applied on an explanatory. As observed 5 border nodes (2, 3, 4, 6, and 11) are selected as CHs. Actually, border and isolated nodes should be considered as undesirable CHs. Our contribution is to overcome these inefficiencies detected in WCA and other similar clustering algorithms. Strong nodes (having three or more neighbors), are better candidates and should be given first priority during the CH selection process. Therefore, we assign selection priorities to the nodes based on their degree in this order*: priority of strong node>priority of weak node> priority of border node* and we set our *node priority aggregation* model. For this purpose, we introduce *the node type indicator (ntype),* which is calculated as follows:

$$ntype(v_i) = \begin{cases} 1, & \deg(v_i) \geq 3 \quad (SN: strong\ node) \\ 2, & \deg(v_i) = 2 \quad (WN: weak\ node) \\ 3, & \deg(v_i) = 1 \quad (BN: border\ node) \end{cases} \tag{3}$$

Next, we formulate our range zone aggregation model.

### 3.2. Range zone aggregation model

We observe that in in [4, 5, 8, 9, 10], the *node neighborhood fidelity* is not taken into consideration in their cumulative weighted formula. By *node neighborhood fidelity*, we mean the ability of neighbors to conserve their neighborhood as long as possible for *a parent node*. A parent node is any CH candidate. Actually, the neighbors can be situated at different distances from their parent node. As this distance increases, the parent node neighborhood fidelity decreases and farther nodes are likely to leave the parent range zone at any time. Consequently, the parent node stability is affected, which decreases its chance to be selected as a CH. Motivated by these observations, we virtually divide the transmission range of a parent node into three virtual zones situated within a circle with radius ***r***: *excellent*, *intermediate* and *risked* zones. The first two zones contain trusted neighbors whose neighborhood is guaranteed for a well-defined period. However, the other neighbor nodes, which are situated in the *risked zone,* are considered as topologically unfavorable (untrusted) nodes because they can be assumed to leave the partition earlier than trusted nodes. To give higher priority to trusted nodes and less priority to untrusted nodes during the CH selection processes, we introduce the following *range indicator* (*rind*):

$$rind(v_i, v_j) = \begin{cases} 1, & dist(v_i, v_j) \leq \alpha_1 r \quad (EZ: excellent\ zone) \\ 2, & \alpha_1 r < dist(v_i, v_j) \leq \alpha_2 r \quad (IZ: intermediate\ \ zone) \\ 3, & \alpha_2 r < dist(v_i, v_j) \leq \alpha_3 r \quad (RZ: risqued\ zone) \end{cases} \tag{4}$$

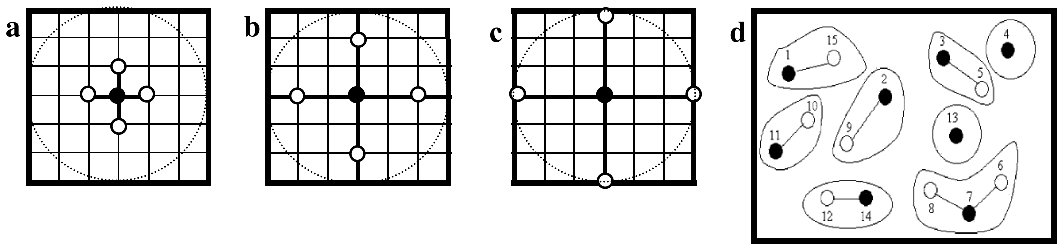


Fig.1. (a) Excellent zone; (b) Intermediate zone; (c) Risked zone; (d) WCA cluster formation stage.

where $\alpha_1$, $\alpha_2$ , $\alpha_3$ are input user coefficients which can be tuned by choosing the suitable values based on the network mobility rate and their sum equals 1. Fig. 1 (a), (b) and (c) depict these types of zones within a transmission range of radius r and virtually divided into three parts.

### *3.3. Node combined indicator model*

Motivated by our previous models, we tried to assure a property which is based on the coexistence of both models. That is, we should select the CH having the maximum degree and having the maximum faithful neighbors situated in the excellent or in the intermediary zones. Based on our two models, we tried to draw binary tables to demonstrate some scenarios which can arise during the CH selection process. In all these tables, number 1 indicates an acceptable combination whereas 0 indicates a rejected one. The node $v_i$ is a parent node and $v_j$ is one of its neighbor. In Table 1 (a), a strong node can be the CH of all neighbors having different degrees. However, a weak $v_i$ cannot be the head of a strong node, but it can head weak and border nodes. A border node can head only border node(s). In Table 1 (b), we discuss the same problem dealing with zone types. As observed, table (b) is similar to table (a), so its cases are discussed analogically. In Table 1 (c), strong or weak $v_i$ can head nodes situated in excellent or intermediate zones, however, a border node can head only nodes situated in the risked zone.

Table1. (a) node behavior according to node type; (b) node behavior according to zone type; (b) node behavior according to node/zone types

| | | $v_j$ (Neighbour node) | | |
|---|---|---|---|---|
| | | **SN** | **WN** | **BN** |
| $v_i$ | **SN** | 1 | 1 | 1 |
| | **WN** | 0 | 1 | 1 |
| | **BN** | 0 | 0 | 1 |

| | | $v_j$ (Neighbour node) | | |
|---|---|---|---|---|
| | | **EZ** | **IZ** | **RZ** |
| $v_i$ | **EZ** | 1 | 1 | 1 |
| | **IZ** | 0 | 1 | 1 |
| | **RZ** | 0 | 0 | 1 |

| | | $v_j$ (Neighbour node) | | |
|---|---|---|---|---|
| | | **EZ** | **IZ** | **RZ** |
| $v_i$ | **SN** | 1 | 1 | 0 |
| | **WN** | 1 | 1 | 0 |
| | **BN** | 0 | 0 | 1 |

The product of the two indicators assures their coexistence, which yields to the new *node combined indicator*:

$$comind(v_i) = ntype(v_i) \times rind(v_i,\ v_j) \tag{5}$$

Next, we take profit of this interesting common indicator, to reformulate many new clustering formulas.

## 4. Quality of Clustering

Motivated by our previous results, we introduce some new parameters assuring the "*Quality of Clustering*" (*QoC*). By *QoC* we mean the idea that cluster characteristics can be measured, improved, and, to some extent, guaranteed in advance. The goal of *QoC* is to provide guarantees on the ability of a cluster to deliver predictable results. The node degree is a very important parameter which is used in many weighted clustering algorithms formulas. Unfortunately, this parameter is passive and does not consider the neighborhood fidelity. Our contribution is to overcome these inefficiencies detected in [2], WCA and other similar clustering algorithms. Based on our proposed node combined indicator, we introduce a new measure which is *"the node quality"* and is calculated as follows:

$$ndq(v_i) = comind(v_i) \times deg(v_i) \quad (6)$$

*4.1. Environmental distance*

As we observed in [2, 5], the distance between parent and neighbour nodes $v_i$ and $v_j$ respectively, is measured without taken into consideration the neighbourhood fidelity. To overcome this inefficiency, and to benefit from our proposed common indicator, we introduce a new measure which is "*the environmental distance*". It takes into consideration the zone where the neighbour node $v_i$ is situated and is calculated as follows:

$$envdist(v_i, v_j) = comind(v_i) \times dist(v_i, v_j) \quad (7)$$

We are motivated to calculate the total environmental distance from a parent node $v_i$ to all the set of its neighbors ($n = |\Gamma(v_i)|$) which are direct linked to it (situated within its transmission range ($R_{v_i}$)):

$$ZD(v_i) = \sum_{j=1}^{n} envdis(v_i, v_j) \quad (8)$$

*4.2. Clustering stability enhancement*

Despite the node mobility in MANETs, the cluster structure should be kept as stable as possible [10]. Otherwise, frequent cluster change or re-clustering adversely affects the performance of radio resource allocation and scheduling protocols [10]. By stability, we mean that the cluster structure remains unchanged for a given reasonable time period [10]. Consequently, we set our stability factor for each node $v_i$ as follows:

$$STF(v_i) = ZD(v_i)/ndq(v_i) \quad (9)$$

In our proposed NQCA algorithm, the neighbor nodes with higher $STF(v_i)$ are considered good candidates to be selected as CHs. The stability of the clustered topology can be achieved by reducing significantly on the number of clusters formed and the number of re-affiliations under different scenarios.

*4.3. Load balancing clustering scheme*

A system can contain high-density clusters and very low-density clusters [11]. In such scenarios the high-density CH will be overwhelmed with processing and communication load, and will consume its energy quickly, while the low density CH will sit idle wasting precious time [11]. Since we assume that all nodes are identical and produce data at the same rate, to balance load in the system we have to balance the number of nodes in a cluster and the communication energy required per CH. For this purpose, we calculate the relative dissemination degree, which reflects the relative deviation of the number of neighbors in a current setting from that ideal [12].

$$\beta(v_i) = |\delta - ndq(v_i)|/ndq(v_i) \quad (10)$$

*where* $\delta \leq 2ln(N)$, is a constraint on the number of nodes that a CH can handle ideally [12] ($N = |V|$).

*4.4. Energy consumption*

In [5] the authors declared that it is known that more power is required to communicate to a larger distance. Therefore, they evaluate the energy consumption. For this purpose, for every node $v_i$, they compute the sum of the distances, $D(v_i)$ with its neighbors ($n = |\Gamma(v_i)|$), as:

$$D(v_i) = \sum_{j=1}^{n} dis(v_i, v_j) \quad (11)$$

Equation (11) does not differentiate between favorable and unfavorable nodes. However, a CH consumes less energy if it is surrounded by favorable nodes. Our contribution is to replace (11) by (8).

*4.5. Remaining battery energy*

We have identified a weakness in WCA. It consists in computing the cumulative time during which a node acts as a CH. This cannot guarantee a good assessment of energy consumption because data communication consumes a large amount of energy and varies greatly from node to node. Conseqently, we adopt a more simplified method. Each mobile node can easily estimate its remaining batterey energy $RBE(v_i)$. Consequently, a node with longer remaining battery lifetime is a better choice for a CH [12, 14, 15, 16, 17, 18].

*4.6. Combined Weight*

Similar to [5], in our NQCA algorithm, the choice of the CHs is based on the weight associated to each node: the smaller the weight of a node, the better that node is for the role of CH.

$$W(v_i) = w_1 ZD(v_i) + w_2 RBE(v_i) + w_3 STF(v_i) + w_4 \beta(v_i) \quad (12)$$

## 5. Our proposed clustering NQCA algorithm

We propose our NQCA algorithm that effectively combines each of the above system parameters with certain weighting factors chosen according to the system needs. The flexibility of changing the weight factors helps us apply our algorithm to various networks [5, 14, 15, 16, 17, 18]. The output of CH election procedure is a set of nodes called the dominant set. The CH election procedure is invoked at the time of system activation and also when the current dominant set is unable to cover all the nodes. Every invocation of the election algorithm does not necessarily mean that all the CHs in the previous dominant set are replaced with the new ones. If a node detaches itself from its current CH and attaches to another CH, then the involved CHs update their member list instead of invoking the election algorithm [13].

*5.1 NQCA structure*

Our algorithm is composed of two parts: CH selection and formation of cluster members' set.

*5.1.1 Cluster head selection*

The CH selection process is depicted in Fig. 2 (a).

*5.1.2 Cluster member formation*

This stage constitutes the final step of our NQCA algorithm and represents the construction of the cluster members' set. Each CH defines its neighbors at two hops maximum, which form the members of the cluster. In the following step, each CH stores all information about its members, and all nodes record the CH identifier. This exchange of information allows the routing protocol to function in the cluster and between the clusters. Because the topology is dynamic, the nodes tend to move in different directions and at different speeds provoking the clusters' configuration. Consequently, the position of the nodes and their speed must be updated periodically. The speed of a node is responsible for the change in its position. For this reason, the speed of the node generates the choice of the update time-slot [5]. Updates can be reduced by choosing longer time-slot, if the mobility of the node is low [5]. We should avoid periodical updates with higher frequency as they provoke great consumption of battery power and consequently increase the necessity of configuration changes [5].

### *5.1.3 Explanatory example*

For a better comprehension of our algorithm, we take an example where the topology is arbitrary and the network is composed of 30 nodes. A node can hear broadcast beacons from the nodes which are within its transmission range. We demonstrate our NQCA algorithm with the help of Fig. 2 (b) and (c). An edge between two nodes in Fig.2 (b) signifies that the nodes are direct neighbors of each other. All numeric values, are obtained from executing NQCA on the 30 nodes are tabulated in table 2, where the combined weight $W(v_i)$ is sorted in increasing order. The degree $deg(v_i)$, which is the total number of neighbors a node has is shown in Step 3. For each node, the energy consumption, the stability factor, the relative dissemination degree and the remaining battery lifetime are calculated in steps 4, 5, 6 and 7 respectively.

Table2. Execution of NQCA

| Node # | Direct neighbor | deg($v_i$) | $stf(v_i)$ | $\beta(v_i)$ | $ZD(v_i)$ | $Remen(v_i)$ | $W(v_i)$ |
|---|---|---|---|---|---|---|---|
| 5 | 3, 4,13 | 3 | 0.35 | 0.1666 | 2.1 | 2 | 1.15 |
| 20 | 18, 19, 28 | 3 | 0.35 | 0.1666 | 2.1 | 2 | 1.15 |
| 1 | 15, 10 | 2 | 0.375 | 0.375 | 3 | 2 | 1.62 |
| 8 | 13, 7 | 2 | 0.375 | 0.375 | 3 | 2 | 1.62 |
| 16 | 30, 25 | 2 | 0.375 | 0.375 | 3 | 2 | 1.4625 |
| 23 | 22, 28 | 2 | 0.375 | 0.375 | 3 | 2 | 1.4625 |
| 9 | 2, 10, 12, 14 | 4 | 0.3 | 0.375 | 2.4 | 3 | 1.4675 |
| 24 | 17, 25, 27, 29 | 4 | 0.3 | 0.375 | 2.4 | 3 | 1.4675 |
| 7 | 6, 8 | 2 | 0.4 | 0.375 | 3.2 | 2 | 1.5275 |
| 22 | 21, 23 | 2 | 0.4 | 0.375 | 3.2 | 2 | 1.5275 |
| 10 | 1, 9, 11 | 3 | 0.35 | 0.1666 | 2.1 | 4 | 1.55 |
| 25 | 16, 24, 26 | 3 | 0.35 | 0.1666 | 2.1 | 4 | 1.55 |
| 13 | 5, 8 | 2 | 0.45 | 0.375 | 3.6 | 4 | 2.0575 |
| 28 | 20, 23 | 2 | 0.45 | 0.375 | 3.6 | 4 | 2.0575 |
| 14 | 9, 12 | 2 | 0.75 | 0.375 | 6 | 1 | 2.375 |

| Node # | Direct neighbor | deg($v_i$) | $stf(v_i)$ | $\beta(v_i)$ | $ZD(v_i)$ | $Remen(v_i)$ | $W(v_i)$ |
|---|---|---|---|---|---|---|---|
| 29 | 24, 27 | 2 | 0.75 | 0.375 | 6 | 1 | 2.375 |
| 6 | 7 | 1 | 0.55 | 0.5833 | 6.6 | 1 | 2.45 |
| 21 | 22 | 1 | 0.55 | 0.5833 | 6.6 | 1 | 2.45 |
| 12 | 9, 14 | 2 | 1 | 0.1666 | 6 | 2 | 2.585 |
| 27 | 24, 29 | 2 | 1 | 0.1666 | 6 | 2 | 2.585 |
| 4 | 5 | 1 | 1 | 0.4444 | 9 | 1 | 3.2 |
| 19 | 20 | 1 | 1 | 0.4444 | 9 | 1 | 3.2 |
| 2 | 9 | 1 | 1 | 0.4444 | 9 | 3 | 3.6 |
| 11 | 10 | 1 | 1 | 0.4444 | 9 | 3 | 3.6 |
| 17 | 24 | 1 | 1 | 0.4444 | 9 | 3 | 3.6 |
| 26 | 25 | 1 | 1 | 0.4444 | 9 | 3 | 3.6 |
| 3 | 5 | 1 | 1 | 0.4444 | 9 | 4 | 3.8 |
| 18 | 20 | 1 | 1 | 0.4444 | 9 | 4 | 3.8 |
| 15 | 1 | 1 | 1 | 0.5833 | 12 | 0 | 3.925 |
| 30 | 16 | 1 | 1 | 0.5833 | 12 | 0 | 3.925 |

Thereafter, we compute the weighted metric $W(v_i)$, for every node as proposed in Step 8 in our algorithm. The weights considered are $w_1 = 0.1$, $w_2 = 0.3$, $w_3$, $w_4$ and $w_5$ are equal to 0.2. Note that these weighting factors are chosen arbitrarily such that their sum equals 1. We set $\delta \leq 2ln(N) = 2\times \ln(30) \approx 7$. As seen from Table 2, the

a

*Input*: G(V,E), neighborhood, distances
*Output*: Set of clusterheads
1. For each node $v_i \in G$
2. Begin
3. Find the neighbors of $v_i$ using (2).
4. Calculate Energy consumption using (11).
5. Calculate Stability Factor using (9).
6. Evaluate Relative Dissemination Degree using (10).
7. Calculate Remaining battery energy.
8. Calculate $W(v_i)$ using (12);
9. $CW \leftarrow W(v_i)$; End
10. Sort $CW$ in increasing order
11. **While CW is not empty**
12. Begin
13. $v_i \leftarrow Cw$; $CH \leftarrow v_i$
14. Delete node $v_i$ from CW and all $\Gamma(v_i)$ from CW
15. End

b c

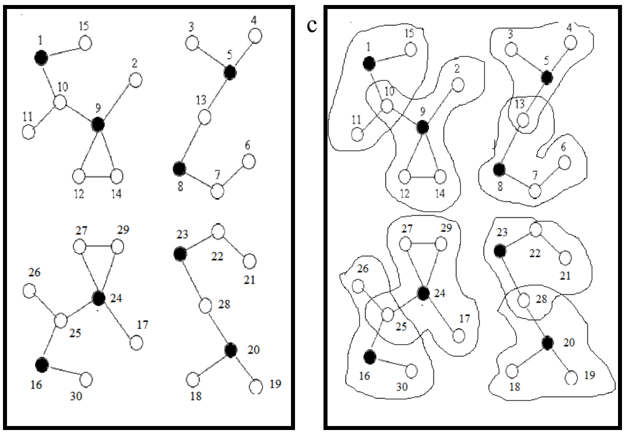

*Fig.2. (a) NQCA algorithm; (b) election stage; (c) Cluster formation stage*

nodes 5, 20, 1, 8, 16, 23, 9 and 24 are selected as CHs. The nodes 10, 18, 25 and 28 are selected as gateways. The contribution of the individual components can be tuned by choosing the appropriate combination of the weighing factors [5]. Fig. 2 (b) shows the selected CHs in a distributed fashion as stated in Step 12 in our algorithm. The solid nodes represent the CHs elected for the network. Note that as a result of Step 14, no two CHs are immediate neighbors. The number of clusters generated by our algorithm (8 clusters) is similar to WCA (8 clusters) for graph containing 15 nodes. This can be explained by the robustness of our parameters used to choose the CH.

## 6. Conclusion

We have considered the problem of constructing a framework for dynamically organizing mobile nodes in wireless ad-hoc networks into clusters where it is necessary to provide robustness in the face of topological changes caused by node motion, node failure and node insertion/removal. We mathematically derived two models which were thereafter combined to get profit of their benefits. Motivated by this combination, we reformulate many node degree based formula given in literature and dealing with Quality of Clustering (*QoS*) as stability and load balancing clustering parameters. These proposed schemes overcome some inefficiencies detected in WCA and other similar clustering algorithms. It was shown that the performance of our proposed clustering algorithm is similar to the best well-known algorithms, such as the WCA.

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