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State-of-the-Art Clustering Schemes in Mobile Ad Hoc Networks: Objectives, Challenges, and Future Directions

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ABSTRACT Mobile ad hoc networks (MANETs) are self-organized networks without any fixed infrastructure. The topology changes are very frequent in MANETs due to nodes' mobility. The topology maintenance creates an extra overhead, as the mobility information of a single node is shared with all nodes in the network. To address the topology maintenance overhead problem in MANETs, the researchers proposed different cluster-based algorithms to reduce the size of a routing table. The clusters are formed to locally adjust the topology changes within the cluster. If a node wants to communicate with a node outside the cluster, it only communicates with its cluster head (CH). The CH communicates with other CHs to transmit data toward the destination. To efficiently utilize the clustering mechanism in MANETs, stable and balanced clusters are required. To form good quality and optimized clusters, some metrics, such as relative mobility (node speed and direction), node degree, residual energy, communication workload, and neighbor's behavior, are required. In this paper, we present a comprehensive survey of recent CAs in MANETs. We also present the objectives, goals, and contributions of recent research. Similarly, the findings, challenges, and future directions are stated. The validation of each proposed work is analyzed critically in terms of the mobility model, the simulation tool used during simulation, simulation metrics, and the performance metrics used in the validation process.

INDEX TERMS MANETs, clustering algorithms, routing, cluster based MANET.

I. INTRODUCTION

Personals from prominent corporations (e.g. IBM) have proposed the post-PC era [1]. In some applications, pre deployed infrastructure such as access points in wireless networks or routers in wired networks are not required. To ensure communication in these applications, MANETs was utilized. A MANET is a self-organizing, wireless network of mobile nodes without any fixed infrastructure. Numerous standardized technologies, such as Ultra-Wideband (UWB), IEEE 802.15.3 [2] (Wireless PAN), IEEE 802.11 [3] (Wi-Fi), Bluetooth [4] support MANET. A MANET allows us to structure a short-term wireless network for immediate communication without any fixed Infrastructure. It can be used in a variety of applications, such as battle field communications, law enforcement, mobile conferencing, disaster relief and emergency rescue. When the size of the network becomes large, a hierarchical network structure outperforms flat structure irrespective of the routing procedure used [5]–[7]. When the nodes are mobile, the scalability issue arises in large scale flat structure. When the number of nodes in a network with flat structure is n, the communication complexity of proactive link based routing mechanism is O (n2) [8]. When the nodes in the mobile network increases, the routing overhead increases with the square the number of nodes. The reactive routing protocols also suffer from the route setup delay and flooding route request (RREQ) packets when the number of mobile nodes in a MANET becomes large. Therefore, to achieve basic performance guarantee in large scale MANET, a hierarchal structure is necessary [9]. Cluster structure is a typical implementation of a hierarchical architecture. Selecting CHs optimally is an NP-hard problem [10].

Since a cluster structure is a typical hierarchy, research emphasis on offering an efficient and effective CA for MANETs. In this article, we presented a survey of various recent clustering mechanisms in MANETs. These schemes are classified and critically analyzed based on the clustering objectives and methodology.

The paper acknowledge some important parameters of network nodes such as remaining energy, relative mobility, degree, reliability, communication workload, reputation and trust during the cluster head selection process. State of the art research is categorized on the basis of different parameters help the young researchers to select their area of interest. The recent proposals on clustering in MANETs are analyzed in terms of cluster head criteria, clustering type, neighbor method, clustering parameters, network partition, and number of clusters, energy consideration, clustering method and re-clustering. The validation of each proposed work is also analyzed in terms of mobility model, simulation tool used in the simulation, simulation metrics and the performance metrics used in the validation process.

II. CLUSTERING SCHEME OVERVIEW

Clustering is a process in MANET in which the mobile nodes are divided into different virtual groups. Nodes are assigned to a group based on some rule. The nodes behavior in a cluster is different from the nodes outside the cluster. The nodes in a cluster are also categorized based on their function, such as CH, cluster member, or gateway node. The responsibility of a CH is to manage the cluster members, handle inter cluster communication and data transmission to the base station. Node within the transmission range of two CHs is known as gateway node. The gateway node can also be used to forward data between neighboring clusters. Any other node other than gateway and CH are member nodes also called an ordinary node.

A. COST OF CLUSTERING

When the size of the network is very large and nodes are freely moving, the clustering structure achieves scalability. Conversely, the CA has its own limitations due to the cluster construction and maintenance. The key challenge to achieve the scalability and efficiency in cluster structure is the cost of clustering. The cost of clustering depends on message exchange among mobile node pairs as frequent messages are required to preserve a cluster structure in a dynamically changing environment [11]–[24]. The information exchange associated when local events, such as the movement or energy drain of a mobile node takes place. Some CAs reform the clusters completely over the whole network and the CHs are re-elected [25]–[33]. The changes in one CH may cause the whole network to re-cluster and the CHs are re-elected [32]. Therefore, the performance of upper layer protocols may be affected due to ripple effect of re-clustering.

Additionally, most algorithms assume static nodes during cluster formation and divide the clustering process to cluster formation and maintenance [27], [28], [30]–[45]. In these algorithms, the nodes invoke the initial cluster formation when it initiates communication with neighbors and declares that it holds some precise characteristics in its locality. This supposition may not be valid in real scenario [25], [64] where the nodes are moving constantly.

B. QUALITY OF CLUSTERING

To achieve good quality clustering structures, the following parameters are considered.

Energy: The node must have enough battery power that handles the load of a cluster. The load on CH is more than ordinary nodes. Connectivity: The number of neighbors of a node represents its degree or connectivity index. The nodes with high connectivity index are the best candidates for the CH role. Maximum connectivity results stability in the clusters.

Mobility: The mobility of a node is the distance of a node from one location to another in specific amount of time. Nodes with the relative mobility (velocity, motion, direction) to its neighbors are suitable candidates for CHs. The nodes with low mobility are suitable nodes to become CHs and may not perform well when the neighbor's mobility is high.

Communication load: The number of packets a node transmits and receives in a certain interval is the communication load on that node. The nodes with less communication load are suitable for the CH role.

Reputation and trust: The nodes with good reputations are suitable for CHs functions. Trust can be calculated by the truthfulness of the nodes in network functions.

Neighbors quality: The node, the neighbors of which will remain for a long time are better candidates for CHs. The neighbor quality can be measured by predicting its future mobility.

C. CLUSTERING PARAMETERS

For classifying the CAs in MANETs, some parameters may major role with respect to the entire clustering process. These parameters can be used for classification and comparison of the CAs under consideration.

Number of clusters (cluster count): The recent work on clustering in MANET focus on cluster formation and CH selection that lead to different number of clusters.

The number of CHs is known in advance in some schemes and the number of clusters is predetermined. The most critical parameter with respect to efficiency is generally the cluster count.

Intra cluster communication: Direct or one hop communication between the CHs and its members is assumed in many clustering architectures. However, a multi-hop communication is often required in situations when the number of nodes in a cluster is large or the number of CHs is limited to some threshold or the transmission range of node in MANETs is short.

Nodes and CH mobility: Stable clusters are achieved when the nodes deployed in the field are static in nature resulting in intra-cluster network will be managed efficiently. When the nodes in the network or CHs are mobile, the membership of nodes should change dynamically, imposing clusters to change over time and possibly need to be maintained continuously. Nodes types and roles: In heterogeneous MANETs, the CHs are high computation and communication nodes. The nodes in the homogenous ad-hoc network have the same resources like energy, memory and computation. The nodes are selected as CHs randomly or based on mobility, remaining energy and degree.

Cluster formation methodology: The recent work on clustering focus on the distributed nature of cluster formation. The cluster formation task is assigned to multiple nodes in the network in a distributed manner where time efficiency is the key design criteria. The earlier schemes focus on centralized cluster formation in which a central coordinator node is used to manage the cluster formation process.

Cluster-head selection: In heterogeneous MANETs, the CHs are pre-determined. In some algorithms, the CHs are randomly selected based on some criteria (such as energy, connectivity index, mobility and communication load) or on a probabilistic manner. Algorithm complexity: The design goal of the most recent clustering schemes is the fast termination of the executed clustering process. Therefore, for most algorithms, the time complexity or convergence rate is constant or depends on the number of CHs. In earlier works, the time complexity depends on the number of nodes in the network.

Multiple levels: The nodes in MANETs are grouped in a hierarchal fashion with multi levels to evenly distribute the energy consumption. The multi-level clustering architecture has great influence when the network size is very large and the communication between CHs is very important.

Overlapping: Overlapping clusters are formed for quick execution of the CA or better routing efficiency. Most of the well-known protocols focus on non-overlapping cluster formation or minimum overlap.

III. HOW TO CLASSIFY CLUSTERING SCHEMES?

Cluster based routing in MANETs can be differently classified. It may be classified as one hop clustering [25], [29], [30], [40], [45]–[53], multi hop clustering [28], [31], [34]–[36], [39], [42], [43], [54], [55], transmission range or signal strength based clustering [32], [33], [56]–[58] and zone based clustering [38]. MANETs can be classified based on a mobility model such as group mobility [51], [56], [59], [60], regular mobility [46] and random mobility [25], [28], [29], [31], [34], [35], [39], [40], [42], [44], [45], [48], [50], [52], [53], [55], [58], [61]–[64]. The nature of events that take place in MANETs has a very strong impact on clustering process and the clustering process can be classified into proactive clustering [25], [26], [28], [29], [32], [43], [46], [48], [50], [52]–[55], [58]–[63], [65], reactive clustering [31], [36], [37], [40], [42], [47], [49], [51], [56], [57], [66] and hybrid clustering [45]. Similarly the nodes of the network can be grouped based on the size of the cluster such as fixed [46], [59], balanced [30]–[32], [37], [57], unbalanced [55] and dynamic or random partition [29], [34]–[36], [39], [40], [42], [45], [53], [54], [64]. In cluster based routing, each cluster may have a CH so the cluster based routing can be classified based on availability of CHs [25], [26], [28]–[30], [32]–[43], [45]–[57], [59]–[61], [64] and the CHs criteria not defined or having no CHs [27], [31], [44], [62], [63], [65], [66]. Clustering can be classified based on CH selection criteria such as node degree [29], [32], [40], [42], [43], [45], [46], [50], [51], [53], [55]–[57], [61], remaining energy [26], [32], [37], [43], [47], [49]–[54], [61], [64], trust value [53], [64], mobility [26], [34], [42], [43], [46], [47], [49]–[51], [53], [56], [60] and predefined CHs [59].

Clustering protocols (CPs) can be generally classified into five categories. First, Connectivity based clustering [26], [29], [35], [37], [40], [42], [43], [45], [46], [51], [55]–[57], [61] the clustering can be formed based on the degree of the CH. Usually, the nodes with highest connectivity are selected as CHs. Second, the cluster is formed based on the node's mobility, such as in Mobility aware clustering [32], [34], [42], [43], [46], [49], [51]–[53], [56], [60]. Nodes with the relative mobility to its neighbors are the best candidates for CHs. For cluster formation, the relative mobility and in some cases the future mobility should be considered. Third factor is the remaining energy of nodes during CHs selection CHs as proposed in [26], [30], [34], [36], [37], [47], [49], [50], [52]–[54], [57], [61], and [64]. Fourth, the nodes reputation and trust are considered during clustering process. Trust and reputation based CAs are discussed in [36], [53], [54], [61], [64], and [65]. Reputation based clustering mechanism is necessary to prevent selfish nodes from un-wanted behavior. Last, multiple metrics are used during cluster formation. In Hybrid routing [26], [37], [42], [43], [46], [47], [49], [50], [52], [53], [56], [57], [61], [64], [91], the metrics such as node mobility, remaining energy, trust value, and connectivity are considered. Taxonomy of clustering schemes is presented in Figure 1.

In our survey, the clustering schemes are classified based different factors. Evolutionary algorithms based clustering [32], [50], [57], [99] is used to form optimized clusters. The protocols work on special scenarios with group mobility in group routing or group mobility based clustering [51], [59]. To prolong the network life and decrease the energy consumption, energy efficient clustering techniques was proposed [31], [37], [44], [47], [54], [62], [66]. To distribute the load on the whole network, load balancing based cluster formation techniques are discussed [38], [90], [99]. To avoid the selfish behavior of nodes during cluster formation and communication process, cooperative and Trust based clustering techniques are explained [36], [53], [61], [64], [65]. Another AI technique to form optimal clusters in MANETs, Swarm intelligence and PSO based clustering are discussed [32], [41], [63], [90], [91]. Mobility has a very strong impact on topology maintenance. Both the CHs and member nodes can move from one cluster to another cluster area. So, Mobility Aware and Stable clustering [is considered [34], [42], [46], [56], [60]. Similarly, in MANETs topology changes

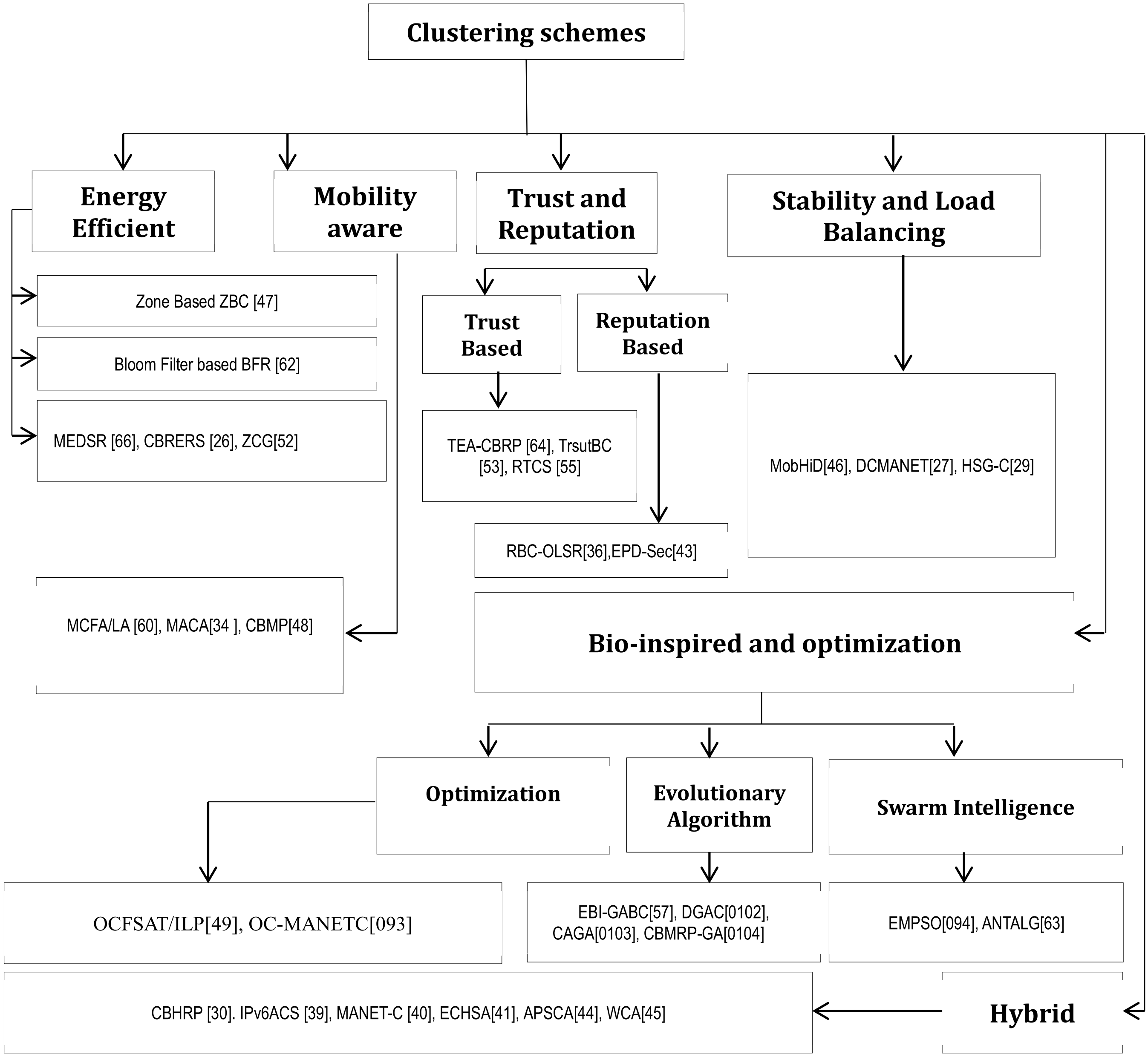

FIGURE 1. Taxonomy of clustering in MANETs.

very frequently due to nodes mobility. To minimize topology changes, stable clusters are formed with less re-affiliation. To reduce the topology maintenance overhead Stable clustering schemes are discussed [27], [35], [40], [45], [55]. A dominated set of CHs is formed and the neighbors near to a CH node joins the cluster in Distributed dominated set and ring clustering [28], [51], [60]. Data replication based [58], Top-k query routing [25], [26], Redundant broadcast and path discovery [52] and QoS based Clustering [48] are other schemes proposed in this area.

IV. CLASSIFYING CLUSTERING SCHEMES

Clustering schemes are classified into different categories such as energy efficiency, mobility, stability, optimization, bio-inspired, evolutionary algorithms and hybrid clustering.

TABLE 1. Energy efficient CH selection parameters.

Ref	Energy	Mobility	Degree	Communication load	Trust
26	YES	YES	YES	No	No
47	YES	YES	YES	NO	No
52	YES	YES	NO	No	No

A. ENERGY EFFICIENT CLUSTERING

The objective of the scheme is to reduce the energy consumption during the cluster formation process. It can be achieved by reducing the re-clustering or re-affiliation of nodes and may increase the network lifetime. The network

TABLE 2. Energy efficient clustering properties.

Ref	Clustering type	Neighbor criteria	Clustering parameters	Partition method	Clustering method	Re-clustering
26	Proactive	M-hop	1-hop	Ring based p	NA	Yes
47	Reactive	One hop	Neighbors join the CH	Different zones	One hop	NA
52	Proactive	One hop	1-hop	Zone based	One hop	NA
62	Proactive	Heat zone	NA	NA	NA	NA
66	Reactive	Transmission power	Hierarchal	NA	NA	NA

overhead should be decreased. The transmission ranges of mobile nodes are adjusted to reduce the power consumption of nodes.

1) ZONE BASED CLUSTERING

The network is divided into zones and the energy efficiency is achieved via controlling redundant broadcast [47]. Minimum energy dynamic source routing (MEDSR) is designed to adjust the power levels of the nodes based on the requirements for energy efficient routing [66]. Bloom filter data structures are used to store the topology information in [62]. Bloom filters are very small in size and can be used for energy efficient routing. A technique proposed in [26] uses expanding ring search procedure to control the broadcast of query packets when the route from source to destination is found.

The papers [62] and [66] did not mention the clustering process. The papers [26], [47], and [52] use low mobility metric for CH selection and if the neighbor nodes are moving with high speed, the clustering process will create more overhead than flat based routing approach. Similarly, earlier approaches did not consider the relative mobility of neighbor nodes during cluster formation.

The nodes are divided into adjacent zones in [47]. A node from each zone is selected as zone leader. The zone leader is selected based on the fitness value adopted in [67].

The nodes with low mobility and high remaining energy are the best candidates for zone leadership function.

In parallel collision guided broadcasting protocol in conjunction with zone based routing is executed to obtain two objectives [20]. First, the redundant broadcasting should be reduced. Second, the routing paths will be discovered quickly. The reachability ratio should be maintained and also the energy consumption will be low. The nodes with high energy power and low mobility are selected as zone leaders and the zone leaders based on this criteria are more reliable.

2) CLUSTERING USING BLOOM FILTERS

The bloom filters are types of probabilistic data structures similar to standard hash tables [62]. These structures can be used to identify the existence of a member in a set or not. The bloom filters can store more data than hash tables. The existence of false positives is allowed in bloom filters. In MANET's, bloom filters can be used for the storage of topological information. Using bloom filters, the control overhead in routing exchanges is reduced and the bandwidth can be used for other purposes. The use of bloom filters in large scale networks requires fewer resources. The TAB filters are used to spread the topology information across the network. TAB filters have small size, have large storage capacity to store binary information and also have the capability to delete the values that have not been updated throughout a definite time. The hop distances are represented by GTAB a stack of TAB filters. It transmits a limited number of control messages in large scale networks compared to other techniques. The protocol results less number of false positives. The data delivery ratio is also high on this approach.

TABLE 3. Energy efficient clustering performance metrics.

Ref	Control overhead	Delay	Delivery ratio	Throughput	Energy
26	NO	YES	NO	YES	NO
47	NO	YES	NO	YES	NO
52	YES	YES	NO	YES	NO
66	NO	NO	YES	YES	YES

3) MINIMUM ENERGY BASED CLUSTERING

Two protocols minimum energy and hierarchal minimum energy based on dynamic source routing (MEDSR) are proposed in [66]. The protocol is basically designed to maintain the network connectivity while the energy consumption should be kept as low as possible. Hierarchal minimum energy based DSR is proposed to reduce the MESDR overhead.

The energy used for overhead packet transmission is reduced and the saving in energy should be used for data transmission. The protocol works in two phases. First, multiple route discovery and power required for transmission on that route. Second, adjustment of power in each link.

The route request packets are used to discover energy efficient routes and rout reply packets are used to adjust the power level required for transmission on that route. The overhead in transmitting packets is significantly reduced and the energy consumption should be reduced. The data packets, energy consumption is also reduced in MEDSR. The route discovery is initiated with low power by the source nodes. High power levels are used for route discovery if the route discovery fails with low power. The neighbors handle route discovery packets differently.

Finding optimal and efficient path from source to destination for data transmission is an important task in MANET routing [26]. The paths may be discovered in a predefined manner or it may be on demand based on the requirement. The query packets are used to discover the optimal paths.

TABLE 4. Energy efficient clustering simulation study.

Ref	Mobility Model	Simulation tool	Compared to	Node Speed	Simulation Area (m2)	Network Size (nodes)	Simulation Time
47	NA	Opnet	AODV[69],	4 to 55 km/h	NA	NA 7NA	
52	RWP	OPNET	NA	NA	NA	NA	NA
62	RWP	Qualnet 5.0	AODV[69], OLSR[71], ZRP	1 to 15 m/s	1800*1800 m	100-3000	NA
66	NA	NS-2	DSR [70]	NA	500-1500(m2)	NA	250 s

The query packets are broadcasted from the source node. The query packets are broadcasted along the whole network, the route has been found. The route discovery packets are prevented from useless broadcast using expanding ring search (ERS) [26]. The network is divided into clusters for achieving scalability and the retransmission of query packets are controlled using a modified version of ERS named Blocking ERS+.

Cluster based routing has the advantage to reduce the energy consumption and prolong the lifetime of the network. Several clusters based routing schemes work on different mechanisms to reduce energy consumption during routing data packets. A node with high energy and low mobility will be selected as CH in [52], but the node may have very few neighbors or no neighbors. A summary of clustering metrics is presented in Table 1, Table 2, Table 3 and Table 4.

Hussain *et al.* [26], Basurra *et al.* [47], and Tarique *et al.* [66] did not mention the mobility model used in the clustering process. Most of the papers assume random mobility and may degrade performance in the absence of random movements.

B. MOBILITY BASED CLUSTERING

The node mobility is the key parameter during cluster formation in cluster based MANET. The nodes move from one location to another, either with random mobility model or in a statistical fashion. The future mobility pattern of node is based on the heuristics that may have a strong impact on the CAs. The node speed and direction known as relative mobility should be considered during cluster formation. If not, the nodes with the same speed with its neighbors, but different direction may be selected as CH and will result in efficient clustering structure but re-clustering will create more overhead. A summary of energy efficient clustering schemes is presented in Table 5, Table 6, Table 7 and Table 8. In MANETs, clustering based on learning automata (MCFA), optimal clusters are formed when we have random node movements with unknown distribution [60]. The nodes are grouped based on the expected mobility pattern. The expected mobility is estimated based on its neighbors. The neighbors mobility samples are taken from time to time to predict the mobility of a node. The nodes are independent to join the cluster as it only looks at the mobility. The algorithm starts its operation by forming initial clusters. The relative speed of the nodes is added as weight in learning automata. The node with high expected weight is selected. This guarantees the cluster stability beside the nodes mobility. The CH is exclusively elected based on its neighborhood information

TABLE 5. Mobility based CH selection parameters.

Ref	Energy	Mobility	Degree
34	YES	YES	No
51	YES	YES	YES
58	YES	YES	No
60	No	YES	No

from the neighbor nodes. To provide better quality of service, the resources can be assigned when needed before any delay in Cluster Based Mobility Prediction Scheme (CBMPS) [48]. To achieve the objective mentioned before, the future mobility of the mobile nodes can be predicted accurately. Min-max algorithm [71], [75] is used for routing with precise mobility prediction. The clusters formed through this algorithm have radius D. Each cluster in the network must have a CH. The member of the cluster is D hops away at maximum from the CH. Each node contains an agent for mobility prediction of the node. The clusters to which a mobile node moves are known as candidate clusters.

The signal strength between two nodes for a time period before the link smashing is used as prediction threshold. There are three types of nodes in this work, first, the link to a central node on the other cluster is greater than PT is central node or it may be a CH. The set of central nodes represents the core. Second, the nodes having a neighbor outside its cluster are known as boarder node. The boarder nodes use the prediction process. The boarder nodes may either leave one cluster or join the other cluster. The boarder nodes have neighbors within the cluster and outside the cluster to which it belongs. Third, the node which is neither central node nor boarder node is known as intermediate node. If the category of node need to be changed or its category is not defined, then the maintenance process is executed. Mobility Aware Clustering Algorithm for Heterogeneous MANET is proposed in [34]. In this technique, the CHs are selected based on node mobility and transmission range. The nodes with low mobility and higher transmission range are the best candidates for CHs. Considering the transmission range and mobility results stable clusters. When the stable clusters are formed, the cluster maintenance overhead should be reduced. The nodes connected through bi-directional links are selected. The members of the clusters are two hops away from the CH so the less number of clusters is formed. The life of the clusters will be long. A summary of simulation analysis is presented in Table 7 and Table 8. In [51], the mobility model was not mentioned. The focus is on packet delivery ratio, throughput and route availability instead of cluster stability, cluster life time and control message overhead. The simulation metrics selected for comparison are not satisfactory.

TABLE 6. Mobility based clustering properties.

Ref	Clustering type	Neighbor criteria	Clustering parameters	Partition method	No of clusters	Clustering method	Re-clustering
34	NA	One hop and two hops	Two Hops	Random	Up to minimal level	Two hop	NA
48	Proactive	Beaconing mechanism	AS in [72]	Distance based	NA	One hop	NA
51	Reactive	Communication range	Relative Mobility	Group based	Not mentioned	One hop	NA
58	Proactive	Signal strength	Transmission Range	Random	Not mentioned	Range leaders	YES
59	Proactive	NA	Neighbors joins the CH	Fixed	Five	One hop/multi hop	No
60	Proactive	NA	Same Mobility	NA	NA	NA	NA

TABLE 7. Mobility based clustering performance metrics.

Ref	Cluster count	Cluster lifetime	Control overhead	Delay	Throughput	Energy
34	YES	NO	NO	NO	NO	NO
48	NO	NO	YES	NO	NO	NO
51	NO	YES	NO	NO	NO	NO
58	NO	NO	NO	YES	YES	NO
59	NO	NO	NO	YES	NO	YES
60	YES	YES	YES	NO	NO	NO

TABLE 8. Mobility based clustering simulation study.

Ref	Mobility Model	Simulation tool	Compared to	Node Speed	Transmission Range	Simulation Area (m2)	Network Size (nodes)	Simulation Time
34	RWP	NS-2 (3.24)	Loose virtual clustering	NA	50/100m	500x500m2	NA	NA
48	RWP	NS-2	DSR [70]	NA	NA	NA	NA	NA
51	Group mobility	Not mentioned	MOBIC[74], DMGA[75]	5-20m/s	300m	1000 1000 m2	NA	NA
58	RWP	NS-2	REALM [76]	5-20m/s	250m	600x600m	50	50 s
59	Group mobility	NS-2	DSR[70], ER[73]	0 to 15 m/s	100m	NA	NA	5,000 s
60	Group mobility	Ns2	AODV[69]	NA	NA	NA	NA	NA

The paper [48], compared results with DSR, AODV and epidemic routing (ER). DSR, AODV and ER are not the cluster based algorithms. The results obtained from the simulations should be compared with related algorithms. The mobility aware CAs may be used for comparison. The simulation metrics used are different in each simulation setup.

TABLE 9. Stable and load balancing CH selection parameters.

Ref	Energy	Mobility	Degree
29	NO	NO	YES
35	NO	NO	YES
46	YES	NO	NO
56	NO	YES	YES

C. STABILITY AND LOAD BALANCING

In [29], a study on stable data transmission using hierarchical share group in MANETs was proposed. The hierarchal sharing group structure (HSGS) decrease the traffic load and the re-formation overhead by continuous streaming service among mobile nodes through secure connection. The nodes are divided into clusters and the node in a cluster with highest degree or maximum number of neighbors is selected as sharing group leader (SGH). The sharing group leader having maximum number of member nodes in its cluster is designated as highest sharing group leader (HSGH). The HSGH manage the node searching module in order to find the location of a node.

Data streaming and relay of continuous monitoring of sharing group members are the responsibility of SGH. The buffer state measurement mechanism is used for data streaming. The sharing group members also forms sub groups with one hop nodes to share the file quickly and reduce network traffic.

In [46], Clustering in MANETs through neighborhood stability-based mobility prediction protocol known as MobHiD was proposed for cluster formation and maintenance instead of fixed geographical partition as in [77], [78], and [79]. First, the future mobility of mobile host is predicted. In comparison to other mobile nodes in the network, the node with low mobility is selected as CH.

The mobility of long time neighbors is used to predict the mobility rate of a mobile host. The nodes with high probability show that the node is moving along its neighbors at the same speed and pattern or is moving with low mobility. It shows that a mobile node will serve its neighbors for long time and is a good candidate to become a CH. It is assumed that the nodes move in a regular pattern not random to correctly predict the future mobility. This can be achieved when we have enough information history of nodes movements. Dynamic clustering in Sparse MANETs, focus on a method to extract cluster development from repeated network snapshots

TABLE 10. Summary of stable and load balancing based clustering metrics.

Ref	Clustering type	Neighbor criteria	Clustering parameters	Partition method	No of clusters	Clustering method
29	Proactive	One hop	NA	Random	Fixed	One hop
35	NA	One and k-hop	K hop clustering	Random	NA	K-hop
46	Proactive	Signal strength	Same mobility	Fixed	As HCDA[93]	One hop
56	Reactive	Transmission zone	Low/high mobility	Zones	Minimum	Signal strength

TABLE 11. Stable and load balancing based clustering metrics performances metrics.

Ref	Cluster count	Cluster lifetime	Control overhead	Re- affiliation	Delivery ratio	Throughput	Computation overhead	Stability
29	NO	NO	NO	NO	NO	YES	NO	NO
35	YES	YES	YES	YES	YES	NO	NO	NO
46	YES	NO	YES	NO	NO	NO	YES	NO
56	YES	YES	NO	NO	NO	NO	NO	YES

TABLE 12. Stable and load balancing based clustering metrics simulation study.

Ref	Mobility Model	Simulation tool	Compared to	Node Speed	Transmission Range	Simulation Area (m2)	Network Size (nodes)	Simulation Time
29	RWP	Ns-2	PSDR[96]	0-200m/s	NA	1000x1000m	50-200	600s
35	RWP	NS-2	KCMM[84], CLSR[85]	3m/s	250m	NA	40	200s
46	Regular	NS-2	Lowest ID (LI) [81], HD [68], GDMAC 102], MOBIC [74].	NA	NA	NA	NA	NA
56	Group	C++	WB[82], PB[83]	NA	NA	15km	400	650s

in a non-disturbing communication manner [27]. The stable and long living clusters are formed to place data and services in a reliable way. The nodes with high re-affiliation can be used for data or service ferries. Different factors that influence the stability of clusters and node cluster affiliation are identified. The results are presented in a different manner. The re-clustering is delayed as much as possible. The re-clustering is initiated based on time or events. The life of a cluster is improved significantly and for both types of delay strategies the lifetime of a cluster converges to almost the same values. The computation required for time based clustering is low and thus a good-looking strategy for clustering. The characteristics of community detection algorithm suitable for sparse MANETs are considered. The algorithms used in the performance are (NG) Newman and Grivan [95], (NM) Clauset et al. [85], (BGLL) Blondel et al. [86], (LP) Latapy and Ponds [87], (vD) van Dongen [88] and (RB) Reichard and Bornholdt [89]. The algorithm is proposed for service placement and data ferry. Low, medium and high are represented by L, M and H in the table respectively, and poor, fair and good are represented by P, F and G.

In cluster-based web service discovery in MANET environments, the stable clusters are formed using mobility metric for CH selection to choose suitable discovery architecture according to the nature of clusters [42].

The suitability of a node to become CH is calculated by considering the connectivity of nodes, sustained duration, velocity and mobility direction. The nodes with high suitability, value are the best candidates for the CHs role. Moreover, it selects a suitable service discovery architecture

TABLE 13. Bio-Inspired and optimize CH selection parameters.

Ref	Energy	Mobility	Degree	Communication load
32	YES	NO	YES	NO
38	YES	YES	NO	NO
49	YES	YES	NO	YES
50	YES	NO	YES	NO
57	YES	NO	YES	NO
93	YES	NO	YES	YES
94	YES	NO	YES	NO
102	NO	NO	YES	NO

based on the characteristics of clusters. In this way, the cluster maintenance messages transmitted are reduced. The number of clusters deleted and created in an environment are reduced compared to existing techniques. This technique forms stable clusters when the nodes are moving in a certain pattern.

Stable clustering architecture reduces the cluster maintenance overhead as the ripple effect is very minimum in this scheme. The number of control messages is reduced and the bandwidth can also be used for data transmission. The CHs selected must have sufficient energy, relative mobile to its neighbors and highest connective to form long living clusters.

The papers present a decent attempt to form stable clusters, but lack important information. The number of clusters and its lifetime can be used for simulation to compare a new technique with existing mechanism but the paper [29] uses transmission delay and network traffic as simulation metrics. The simulation tool used in paper [56] is c++ and is not discussed why this tool is used for simulation, although different simulators are available for analyzing MANETs.

TABLE 14. Summary of bio-inspired and optimization based clustering metrics.

Ref	Clustering type	Neighbor criteria	Clustering parameters	Partition method	No of clusters	Clustering method	Re-clustering
32	Proactive	NA	Same mobility	Balanced	Optimum	Transmission range	Very low
38	Proactive	NA	Within Zone	Random	Fixed in advance	Zone based	YES
49	Reactive	One hop	NA	Traffic	Optimum	One hop	NA
50	Proactive	1-hop	Neighbors	Random	Not mentioned	One hop	NA
57	Reactive	Transmission range	NA	Balanced	NA	Transmission range	No
63	Proactive	NA	NA	NA	NA	NA	NA
93	Proactive	Transmission range	Neighborhood	Balanced	Optimized	Transmission range	Yes
94	NA	Transmission range	Tranmission range	Large clusters	NA	Transmission range	No
102	NA	Transmission range	NA	Balanced	NA	Transmission range	No

The clustering based architecture should be compared with CA. A summary in tabular form is depicted in Table 9, Table 10, Table 11 and Table 12.

D. BIO-INSPIRED AND OPTIMIZATION BASED CLUSTERING

The techniques inspired from biology are used to obtain optimal clusters in MANET.

1) CLUSTER OPTIMIZATION

In optimizing communication in MANET clustering, the algorithm optimizes the number of the neighbor node (degree), the lifetime of the cluster, the energy consumption and the communication work load [90]. Regardless of whether a node is CH or an ordinary node, it must participate in communication. The communication load of each node is different from other nodes in the network. The CH nodes communicate with other nodes to monitor the cluster and accommodate the topology changes on top of its own communication. Considering other parameters are same, a node with low communication work load is selected as CH. The node degree, energy and the remaining lifetime of a node and communication load are optimized to form balanced clusters. The algorithm runs on a single node picked from network having high power. Each node has the capability to measure the distance to its neighbors or have a GPS and store it. Integer linear programming and Boolean satisfiability are used to address the clustering problem in optimizing complex cluster formation in MANETs using SAT/ILP techniques MANETs [49]. It presents several enhancements in the form of extensions. These enhancements are the enforcement of coverage, multi hops connections and communication within clusters. The network topologies are created visually in a tool and then clustering is performed using SAT and ILP solvers. The algorithm is evaluated in various real life practical environments. The 0-1 SAT based ILP and BSOLO are best for small networks and SCIP, CPLEX and Generic ILP solvers are used to handle large scale networks.

TABLE 15. Bio-inspired and optimization based clustering performances metrics.

Ref	Cluster count	Cluster life-time	Control over-head	Delay	Delivery ratio	Throughput	Energy
32	YES	NO	NO	NO	NO	NO	NO
38	NO	NO	NO	NO	NO	NO	NO
49	YES	YES	NO	NO	NO	NO	NO
50	YES	NO	YES	NO	YES	NO	NO
57	NO	NO	NO	NO	NO	NO	NO
63	NO	NO	NO	YES	NO	YES	NO
93	NO	YES	YES	NO	NO	NO	NO
94	YES	NO	NO	NO	NO	NO	YES
102	NO	NO	NO	NO	NO	NO	NO

2) SWARM INTELLIGENCE BASED CLUSTERING

In ANTALG: An Innovative ACO based Routing Algorithm for MANETs, the selection of source nodes one by one from the network list to create routing tables consume a huge amount of time [63]. The source nodes are selected for transmission randomly from a set of nodes to save the time and to form the pheromone table. It is the basic nature of MANET that some nodes did not participate in communication. To reduce route discovery time, all nodes should not act like source nodes. Because of evaporation and new pheromone, the proposed solution is adaptive in nature. The highest pheromone value obtained from iteration is used. This value helps in achieving local maxima. The global pheromone value is updated by using the computation in the beginning.

In energy-efficient clustering in MANETs using multi-objective particle swarm optimization, swarm intelligence was used to optimize clustering in MANETs [91]. It prolongs the network lifetime by reducing the energy dissipation, optimization of the number of clusters to form the stable network structure and to reduce the network. The CHs manage the overall traffic within the cluster and between clusters. The CHs are selected based on remaining energy, transmission power and connectivity index. The algorithm starts with a random CH set T chosen based on IDs. Each set covers the whole network and the IDs are not repeated. Each of these

TABLE 16. Bio-inspired and optimization based clustering metrics simulation study.

Ref	Mobility Model	Simulation tool	Compared to	Node Speed	TransRange	Simulation Area (m2)	Network Size (nodes)	Simulation Time
38	NA	NA	NA	0-10m/s	100m	1000x1000m	250	NA
49	NA	CPLEX [98], SCIP [99], BSOLO [78], Pueblo [100][101]	NA	NA	NA	NA	NA	NA
50	RWP	NS-2 2.34	WCA[95], GAWCA [103], GACBMRP[104], ODMRP	NA	700m	1000x1000m	200	NA
57	NA	NA	Restart GA, standard GA, random immigrants GA.	NA	NA	200x200m	NA	NA
63	RWP	ns-2 (version 2.33)	AODV, ADSR and HOP-NET	10-35m/s	NA	1500x1500m	100	NA
93	RP	NA	WCA[95],GA,SA[96]	NA	NA	500X500Km	100	1000S
94	NA	MATLAB 7.8.0	CLPSO [97] and WCA[95]	NA	NA	1000X1000m	NA	NA
102	NA	NA	Dynamic Gas	NA	50	200x200m	100	NA

particles is complete and unique. It covers the whole network and each cluster have a unique CH. The objective function is optimized for each solution. The working mechanism of the algorithm is; first, the CHs neighbors are identified their mobility, energy, and transmission range is calculated. The result of the objectives of the current and previous solutions is compared and a CHset with high objective value is chosen. The proposed approach is flexible in the sense that it provides multiple solutions. The user selects a solution according to the network requirements. In this way, the routing overhead is reduced by reducing the number of clusters. It can search the large space. The objective values can be adjusted dynamically in this approach.

In this section, swarm intelligence is used to form and stable clusters in MANETs and optimize the objective function for different network environments. Multi objective cluster formation is an optimization problem in large scale MANETs. Artificial intelligence can be used to solve optimization problems. One well known and widely used technique in different subjects is swarm intelligence. The beauty of this approach is the collective work of particles to form an optimal solution to a problem. The algorithm runs in a cooperative manner to achieve the global solution. The solution depends on the parameters selected. When the parameter selection is decent, the solution will be optimized. The clustering metrics are presented in Table 17, Table 18.

TABLE 17. Ch selection parameters (hybrid clustering).

Ref	Energy	Degree
30	YES	NO
39	YES	NO
40	NO	YES

3) EVOLUTIONARY ALGORITHMS BASED CLUSTERING

The algorithm first design the components of the standard genetic algorithm (SGA). To deal with the environmental dynamics, several multi population schemes, memory, immigrants and their combinations is integrated into SGA. To maintain the diversity, a number of immigrants are created and added into the population at each generation. To address the problem of load balancing, specialized genetic algorithm known as a standard genetic algorithm (SGA) and restart genetic algorithm (RGA) are used. In standard approach the special actions are not taken during environmental changes. The fitness values for each individual is evaluated based on the new environment. In restart genetic algorithm, the entire population will be re-initialized when a topology change occurs.

Evolutionary algorithms form balanced clusters to even the energy consumption in all parts of the network [57], [99]–[101]. When a protocol assumes more than one metrics like energy, degree and mobility becomes an optimization function. The multi objective optimization problems can be addressed using evolutionary algorithms like genetic algorithm.

The genetic algorithm suffers from local maxima, so some paper use immigrants, to obtain the global optimal solution. GA is very useful to solve dynamic optimization problems, but the papers reviewed in this section have some challenges that need careful attention.

In a simulation study (Table 15 and Table 16), the nodes moving pattern are very vital to form balanced cluster network and is not stated in [14], [38], and [56]. The simulation metrics adjusted during the simulation are not revealed in [57]. The clustering metrics are summarized in Table 13 and Table 14.

E. HYBRID CLUSTERING

MANETs can be deployed in a range of applications like military operation and rescue management. Every application has different requirements and a cluster based routing technique cannot be applied to all applications.

In Cluster Based Hybrid Routing Protocol (CBHRP), distrusted spanning tree is used to for disjoint hierarchal cluster formation in MANETs [30]. The first step in this algorithm is to organize the nodes into a set of disjoint hierarchical clusters and then hybrid routing is performed for routing packets from source to destination node in the network. The route discovery will start after the successful cluster formation.

TABLE 18. Summary hybrid clustering metrics.

Ref	Clustering type	Neighbor criteria	Clustering parameters	Partition method	No of clusters	Clustering method	Re-clustering
30	Hybrid	1 hop	CH Message arrival	Balanced	Minimum	One hop	YES
31	Reactive	Transmission range	MEP receive	Balanced	Upper and lower bound	Multi hop	YES
33	NA	RF based	Two random clusters	NA	Two	Transmission range	No
39	Proactive(address configuration only)	One hop	Tree based	Random	NA	Multi hop	YES
40	Reactive	One hop	High degree	Random	Not known	One hop	YES

TABLE 19. Hybrid clustering performance metrics.

Ref	Cluster count	Cluster lifetime	Control overhead	Re affiliation	Delay	Delivery ratio	Throughput
30	YES	NO	NO	NO	NO	NO	NO
31	NO	NO	NO	NO	NO	YES	NO
33	NO	NO	NO	NO	NO	NO	YES
39	NO	NO	YES	NO	YES	NO	NO
40	YES	YES	NO	YES	NO	NO	NO

The nodes within the transmission range of CH communicate directly instead of data forwarding to the CH. The merging procedure is activated when the number of nodes in a cluster is below a certain threshold. The cluster is merged with neighbor cluster to balance the energy consumption in the network. To increase the routing efficiency, the leaf nodes also maintain and store neighbors information.

Cluster-Based and Distributed IPv6 Address Configuration Scheme for a MANET was proposed for IPv6 address configuration and for the parallel configuration in different parts of the network [39]. The network is first divided into different clusters after deployment and each cluster starts its address configuration. A cluster based address configuration scheme is proposed in order to achieve the lowest latency and low cost address configuration for all nodes in the network. To shorten the delay and reducing the cluster configuration cost, the address configuration is started simultaneously with the cluster formation process. In this way, the hierarchal address structure is created.

The member nodes in a cluster acquire the addresses from the CHs and perform the address configuration in a distributed manner. Different cluster performs configuration in parallel so it shorten the delay and scalability is improved. In order to ensure collision free MANETs, the splitting/ merging algorithm was proposed.

In Constructing a MANET Based on Clusters, the clusters are formed based on the possible cluster members and the node with maximum number of neighbor nodes are selected as CHs [40]. The cluster size is maximized and the number of clusters and CHs are minimized. To ensure communication between CHs, only one node is associated for this purpose. The number of nodes in the backbone is minimized and the stable clusters are obtained.

When two CHs are within the communication range of each other, the cluster merging procedure is invoked. This merging process helps in maintaining the minimum number of CHs. When a CH fails or leaves the cluster, the cluster repairing algorithm is invoked and the stable clusters are formed.

In Efficient CH Selection Algorithm for MANET, artificial intelligence is used to select CHs efficiently in MANETs [41]. The CH nodes are selected based on minimum packet loss ratio and its behavior in network functions. The node with minimum packet loss ratio and cooperative behavior become CHs. Populating the B and W list, the algorithm selects the heads with AI capabilities. Hence, less resources are consumed in the selection process. When a node is elected as CH, it is compulsory for that node to notify all registered nodes in the cluster about its selection. The member nodes are required to revoke their authorization with newly elected CH. In this way, the energy consumption is minimized in this approach.

In Analytical performance of soft clustering Algorithms, the protocol used in medium access layer indicates the success of MANETs [44]. To make best use of channel resources, the parameters at MAC layers should be judged carefully depending on the requirements of the network under consideration. To find the optimal values for the variables, the typical method used is extensive simulation. This approach requires a huge amount of time and processing power. When the size of the network becomes large, the validation time and power required will grow exponentially. To address the issue discussed above, an analytical model that mirrors the relation between the overall performance of a protocol on different network environments and the protocol parameters was proposed in [44]. The approach is designed for TDMA

TABLE 20. Hybrid clustering metrics simulation study.

Ref	Mobility Model	Simulation tool	Compared to	Node Speed	Trans Range	Simulation Area (m2)	Network Size (nodes)	Simulation Time
30	NA	NA	[105]	NA	NA	NA	NA	NA
31	RWP [106]	QualNet ver.5.0	[107] [108], [109]	NA	200-250 m	1500x1500m	200	10 times
33	NA	NS-2.35	[69],[110],[11 [71]	NA	NA	1000x3000m	NA	200s
39	RWP	NS-2	[112] and [113]	5m/s	100m	NA	50-300m	2000s
40	RWP	NS-2	[114]	5-15m/s	20-50m	100x100m	40-80	600s

based clustering. In this model, the node density to the expected number of collisions and packet dropped relates to the TDMA frame parameters (number of frames per super frame, slots per frame).

In A novel weight based clustering algorithm for routing in MANET, the CHs are selected based on node degree and available bandwidth [45]. The clusters are constructed based on the bandwidth requirements. The merging procedure is initiated when two clusters come nearer to each other. One CH will become a member node in the cluster resulted after merging process. A novel procedure for merging two clusters presented. The packet loss is also reduced and stable clusters are achieved. To summarize, Table 17 and Table 18 reflect clustering metrics and simulation study is presented in Table 19 and Table 20.

V. CONCLUSION AND FUTURE DIRECTIONS

MANETs can be deployed in a range of applications like rescue scenarios, military operation and surveillance. Flat network structure suffers from topology maintenance overhead since changes in topology is shared with all nodes. It has a large control message overhead when the network size is very large. To reduce the topology maintenance overhead, the network is divided into clusters. The topology changes are accommodated locally in this approach and thus the control messages are reduced. Many researchers proposed cluster formation algorithms to divide the network into clusters. In this survey, recent research on CAs in MANET is considered and analyzed. The objectives and findings are summarized and presented in tabular form. The parameters (like CH selection criteria, clustering type, neighbor method, clustering parameters, partition type, number of clusters, energy consideration and re-clustering) of all the papers are summarized and critically discussed. The simulation related data (like the mobility model used, simulation parameters, and simulation metrics) are presented. In conclusion, the CAs should be designed based on the most important parameters. These parameters are, nodes remaining energy, degree, relative mobility (direction, speed), communication load, trust, reputation and neighbor's quality. In order to form quality clusters, the clustering scheme should consider maximum parameters during cluster formation and CH selection process. The CH selection based on more than one parameter is a multi-objective optimization problem. Any multi-objective optimization technique (like evolutionary algorithms, swarm intelligence, neural networks, fuzzy logic, game theory, etc.) can be used to form stable and balanced clusters based on the parameters mentioned above.

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