A Survey of Cluster Based Routing Protocols for Mobile Ad-Hoc Sensor Network

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***Abstract*— Mobile ad-hoc and sensor network (MASNET) is a collection of mobile sensor nodes connected via wireless links which can dynamically establish a temporary network of their own, when required, without relying on pre-existing infrastructure. However, mobility of the nodes poses some substantial threats in the network such as power draining and frequent change of the network topology. Due to the dynamic nature of this network, routing of packets is very challenging. Keeping this in mind, we have carried out an extensive survey on various state-of-the-art cluster based routing techniques for MASNET .In this paper, a comprehensive survey on cluster based routing protocols in MASNET are presented with focus on the advantages and disadvantages of each routing protocol. Energy consumption, end-to-end delay, throughput, and packet delivery ratio are some of the parameters that play a significant role in determining whether a routing protocol is efficient or not.**

***Index Terms*—MASNET; Clustering; Inter-Cluster; Intra-Cluster; Hybrid Routing Protocols.**

I. Introduction

Mobile ad-hoc and sensor network (MASNET) is a collection of mobile sensor nodes connected via wireless links. This network is a variation of wireless sensor network (WSN) but also significantly different from WSN. Unlike WSN which requires a pre-existing infrastructure, MASNET is infrastructure less and also a temporary network. This means that the mobile nodes can dynamically establish a temporary network of their own, when required, without relying on pre-existing infrastructure.

In MASNET, the efficient routing protocols are vital to allow high quality data transmission among the nodes. However, to maintain flexibility, these networks are usually constrained in terms of resources such as battery power, memory, bandwidth, etc. Besides that, routing becomes difficult due to the dynamic nature of the networks. Thus, to ensure continuous data communication, routing protocols should not only improve the quality of services but also must address resource limitation in MASNETs. The focus of this paper is to offer a survey of different cluster based routing techniques that have been proposed by researchers.

II. Routing Protocols

Routing protocols define a set of rules by which the data packets are routed or transmitted from the source to the destination node in a network. Generally, routing protocols in MASNETs can be generally categorized as proactive, reactive and hybrid routing protocols.

Despite the number of different routing protocols existing for MASNET, the goal of each protocol remains the same, which is maximize the throughput while packet loss, overhead, and energy usage is minimized.

Apart from the general classification of routing protocols, there are other types of routing protocols or algorithms that are based on the network structure, namely flat routing, location or geographic based routing and hierarchical routing as shown in Figure 1. To provide efficient packet routing, the network is usually structuralized as flat, geographic, or hierarchical.

In a flat routing, all the nodes are equal and have the same role. Flat routing schemes can be categorized as reactive and proactive routing protocols. Geographic or location based routing algorithms require each node in a network be equipped with Global Positioning System (GPS), which will provide position information to every other node. However, this information may not be that accurate by the time it is utilized as MASNET is highly mobile. Hierarchical routing adopts an organization among nodes wherein different nodes have distinct roles in the network. The main goal of hierarchical protocols is toreduce the control packet overhead which increases as the network size increases.

In the hierarchical protocol, the network is divided into clusters or zones. Each cluster is maintained by a cluster head which is selected based on certain criteria. Nodes in the higher hierarchy provide special services to the nodes in the lower hierarchy, such as data aggregation. Hierarchical routing protocols can be divided into inter-cluster communication, intra-cluster communication, and hybrid communication which combines both inter-cluster and intra-cluster communications.

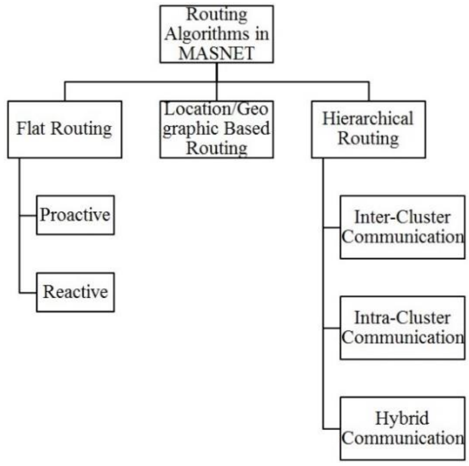

Figure1: Routing Algorithms Based on Network Structure

III. CLUSTER BASED ROUTING PROTOCOLS

In this section, we focus on the cluster-based hierarchical or also known as cluster based routing protocols proposed for MASNET. A special algorithm is used for cluster head election and mobile nodes are grouped based on geographic proximity [1]. Cluster head is responsible for routing operation and node management. Cluster-based protocols are normally able to support a multi-cluster structure of a network. In the following subsection, the latest existing clustering algorithms are reviewed to investigate any insights of these algorithm that can be further used for the enhancement of any cluster based routing protocols.

A. Virtual Links Weight-Based Clustering (VLWBC) algorithm

In [2], the researchers proposed a novel clustering algorithm for mobile ad hoc networks (MANETs) based on the determination of virtual links' weight to increase network stability known as Virtual Links Weight-Based Clustering (VLWBC). This algorithm determines the node's weight using the node's own features and also considers the direct effect of adjacent node's features. Using this technique, cluster heads are chosen based on the highest weight. The cluster maintenance phase has a solution for problems like a node leaving its cluster range, cluster heads failing due to power depletion, member nodes failing due to power depletion, and cluster head interferences.

B. CDCA-TRACE algorithm

In [3], the researchers focused on load distribution in MANETs. Most of the time, the network load is distributed non – uniformly due to node mobility and dynamic nature of the network. They proposed two algorithms to address this problem, a lightweight distributed dynamic channel (DCA) algorithm and a cooperative load balancing algorithm. These algorithms increase the service levels and throughput while reducing the average energy consumption.

C. New Clustering Scheme

In [4], the authors focused on the communication workload of mobile nodes as well as the additional workload of cluster heads in MANETs clustering. Therefore, they proposed an algorithm that optimizes communication workload, power consumption, cluster head lifetime, and node degree. This algorithm results in lower communication workload and longer duration for cluster heads. However, each time this algorithm is run, the entire network is re-clustered which implies overhead to nodes in the network. This drawback has a potential effect on the network lifetime in the long run.

D. Energy – Efficient Cluster Based Routing Protocol (EECRP)

In [5], the authors aimed to reduce energy consumption in cluster based routing protocol by incorporating network coding technology into CBRP. This work presents a network coding – aware, energy – efficient cluster-based routing protocol (EECRP) for MANETs. The authors applied network coding only at the cluster heads in order to reduce computational overhead. This algorithm is designed to improve the performance of CBRP in terms of energy consumption and cluster lifetime by reducing the energy consumption. Network coding is applied to the cluster heads to reduce the number of transmissions and the energy consumption.

E. Grid Based Dynamic Energy Efficient Routing (GBDEER) approach

In [6], the authors proposed a novel grid-based dynamic energy efficient routing approach (GBDEER) for highly dense MANETs. The proposed routing approach aims to avoid network partition and allow communication to take place for longer period. The authors combine two different ideas into the proposed work, i.e. Geographic Adaptive Fidelity (GAF) and minimum spanning tree. By using GAF, "virtual grids" are created and classified into distinct levels. In this proposed work, only one node is active at any one time while the rest are set to sleep to save energy dynamic change of transmission power is also introduced.

F. New Cluster Based Broadcast Algorithm with Dual Coverage Broadcast (DCB) algorithm

In [7], the authors proposed a new cluster based broadcast algorithm that groups nodes into a number of overlapping clusters. This mechanism uses the principle of dual coverage broadcast to improve packet transmission and reduce the number of acknowledgement packets in transmissions. The proposed mechanism provides a high packet delivery ratio and lower energy consumption. The drawback of this algorithm is that it uses a base station as an intermediary node for communication between cluster heads where the authors did not consider the distance of the base station to each cluster head which could increase the energy consumption to transmit packets to another cluster.

G. Intra-cluster Routing Protocol with Back-up Path

In [8], the authors proposed a reactive intra-cluster routing protocol with back-up path for energy efficiency, lifetime awareness and higher network throughput. This protocol consists of two phases, i.e. cluster formation and route determination. In cluster formation phase, a command node (CN) with permanent electricity supply selects a CH for each round of data transmission. CN is also responsible for construction and distribution of routing table to each cluster. In route determination phase, CH sends all member sensor nodes position, energy level, throughput, delay, SINR, and packet loss ratio to CN. CN then uses greedy method to find out the best hop-by-hop data dissemination path and also finds alternative next-hop node for reliable data transmission.

H. Velocity Energy-efficient and Link-aware Cluster-tree (VELCT) scheme

In [9], the authors proposed a Velocity Energy-efficient and Link-aware Cluster-Tree (VELCT) scheme for data collection in mobile WSNs to minimize the problems of coverage distance, mobility, delay, traffic, tree intensity, and end-to-end connection. VELCT consists of two phases, i.e. set-up phase and steady-state phase. In set-up phase, cluster formation takes place and data collection tree (DCT) construction is begun to identify the optimal path between cluster members and sink (intra-cluster). The steady-state phase is then initiated to transfer data from cluster member to sink (inter-cluster). From simulations, VELCT is found to provide more stable links, better throughput, energy utilization and PDR with reduced traffic.

I. Renovated Cluster Based Routing Protocol (RCBRP)

In [10], the authors proposed a Renovated Cluster Based Routing Protocol (RCBRP) to reduce routing overhead and improve routing discovery. The authors integrated inter-cluster on-demand and intra-cluster table-driven routing to increase throughput. In intra-cluster routing, each node forms an intra-cluster routing information table. This is done so that the locations of each node, next hop nodes, and the required hops are known to other nodes. This helps to determine the route. In inter-cluster routing, the source node sends a request packet to its gateway node to obtain routing information within the adjacent clusters. Through simulation, RCBRP is found to enhance throughput, PDR and reduce routing overhead, average end-to-end delay better than AODV.

J. Poly-Meshed Routing Protocol (PMRP)

In [11], the authors proposed this algorithm to overcome the problem of scalability as a network grows larger. This protocol uses mesh tree concept and aims to minimize control overhead while maintaining connectivity robustness and scalability. To address the scalability problem, PMRP uses hierarchical address structure. PMRP has two phases, i.e. cluster formation and routing. In cluster formation phase, a CH is elected based on the highest degree of neighbours. In intra-cluster routing, each node maintains a table of next hops/subnet and updates these tables periodically. When a source sends a route request, CH extracts the destination VID and compares it with its own VID. If they are identical, then intra-cluster routing is initiated. If else, inter-cluster routing is initiated.

K. Loose-Virtual-Clustering-Based Routing for Power Heterogeneous MANETs (LRPH)

In [12], to address the issue of severe impacts of high-power nodes, the authors proposed a novel hierarchical structure that is maintained in the loose-virtual-clustering-based (LVC) algorithm, where the unidirectional links are detected. They developed routing algorithm to avoid packet forwarding via high-power nodes. LRPH consists of two core components, LVC algorithm and routing. In the LVC algorithm, bidirectional nodes (BN) are discovered using a BN discovery scheme. Backbone nodes (B-nodes) are chosen as the CH and maintain a loose coupling relationship with the general nodes (G-nodes). In the routing phase, the packet will be sent directly to the destination node if the route is available in the cache of the source node. Otherwise, the route is discovered by broadcasting a RREQ packet and exploiting the large coverage area of B-nodes.

L. Clustering Algorithm Based on Residual Energy Difference Ratio (CAREDR)

In [13], the authors present a new clustering algorithm based on residual energy difference ratio to improve the system performance of mobile sensor networks (MSNs). The CHs are selected based on the residual energy difference ratio. This technique guarantees that the sensor nodes with higher residual energy have higher possibility at being selected as a CH. In the cluster formation phase, the authors introduce characteristic distance to optimize power and balance the energy consumption. The sink dynamically clusters the sensor nodes according to the data transmission delays, making the entire system adaptive to the dynamic environment of MSNs. The authors introduced ACM scheme into MSNs to choose the channel’s data rates and developed a clustering algorithm which is a dynamic process in clustering the networks.

M. Energy Efficient and QoS Aware Routing Protocol (EEQR)

In [14], the authors proposed a new protocol called Energy Efficient and QoS aware Routing (EEQR) protocol for clustered wireless sensor networks to address the issues of energy efficiency due to hotspots, high end-to-end delay, and QoS in the network. To address the problems of hotspots and high end-to-end delay, a combination of static and mobile sink is used for data gathering. To ensure QoS for different traffic types, prioritization of data is used based on the message type and content. Using this protocol, delay sensitive messages are sent through the static sink while delay tolerant messages are sent using the mobile sink.

N. State-Aware Link Maintenance Approach (SALMA)

In [15], the authors introduced a new hybrid routing approach called State-Aware Link Maintenance Approach which combines both reactive and proactive protocols to reduce overhead and increase network performance by reducing the load of network discovery flooding. The protocol defines the sensor nodes into three states which are determined using Keep Awake Buffer: (a) black nodes – aware and active nodes, (b) grey nodes – aware but not performing data transfer except data forwarding, and (c) white nodes – idle and do not keep any routing information. SALMA protocol develops the routing table, stored in nodes reactively. The route is maintained proactively once a node starts its operation to minimize the flooding of control packets for route discovery and delays in packet transmissions. Nodes that are not involved in data transmission are kept non – active to reduce resource consumption. It uses DSR protocol for initial route discovery and OLSR protocol for route maintenance.

O. Mobile sink – based improved algorithm for Stable Election (MSE)

In [16], the authors proposed a modified Stable Election Protocol (SEP) that employs a mobile sink in WSNs with non-uniform node distribution to address the issue of hotspot due to fixed sink. In this algorithm, the mobile sink is placed along the centre of the sensing field and moves along the trajectory line. The network is divided into several clusters based on SEP. CHs are elected based on the minimization of the associated additional energy and residual energy in each node. The mobile sink moves and gathers packets from CHs. MSE consists of route setup phase, route steady phase, and route maintenance phase. In the route setup phase, CH selection and cluster formation are undertaken. In the route steady phase, the CHs sleep after all the data is gathered, to reduce energy consumption. To avoid collision, the authors define the movement of the mobile sink through the trajectory to be a round. In the route maintenance phase, procedure of calculating the next-hop for normal CH is done. This occurs in case of the death of advanced CH or if the advanced CH is blocked.

P. Stable K-Hop Clustering Algorithm (SKCA)

In [17], the authors proposed a new stable K-hop clustering algorithm which offers a stable cluster topology and reduces the control overhead. This algorithm proposes a new cluster maintenance function which allows two CHs to co-exist in the K-hop neighbourhood in certain situations. It also proposes a new two-round CH election to minimize the distribution of the cluster information in the K-hop neighbourhood. The nodes which are not CHs in their one-hop neighbourhood in the first round are rejected from participating in the second round because these nodes are not potential CH candidates in their K-hop neighbourhood.

Q. Weight based Energy Aware Hierarchical Clustering Scheme

In [18], the authors presented a hierarchical clustering algorithm that is based on relative mobility and merging which depends on mobility pattern. The authors proposed this idea to offer a minimum energy wastage and stability in the network. The proposed algorithm also uses different weights for CH election such as power of nodes, mobility, size of clusters, and degree of nodes. The main aim of the proposed algorithm is to configure optimum number of CHs with optimum number of cluster members to deliver high QoS in the network. Merging of clusters is done when clusters have similar mobility pattern. This is done in a hierarchical manner to decrease the reaffiliations and create a stable network.

R. Fuzzy Logic-Based Clustering Algorithm

In [19], the authors presented a fuzzy logic-based clustering algorithm which elects a super-CH (SCH) among the available CHs in the network, to send information to the mobile BS. The motivation of SCH election is to reduce the energy consumption and improves energy efficiency. SCH is chosen based on fuzzy descriptors such as remaining battery power, mobility and centrality of node. SCH sends data to BS by reducing the number of retransmissions performed by normal CHs.

S. Optimal Weighted Cluster Based Routing Protocol

In [20], the authors modified weighted clustering algorithm (WCA) to select the best routing path through the clusters using fuzzy logic. This algorithm is comprised of three phases. The first phase detects malicious nodes in the network and eliminated to improve the network performance. The second phase includes weight calculation and clustering which calculates the weight of parameters such as node degree, distance to the neighbour, mobility, and battery power to select a CH. This phase also introduces a stability factor to maintain the stability of the clusters. The third phase is the route optimization which chooses the best path using fuzzy logic. Fuzzy system consists of three parts, which are fuzzification, inference engine, and defuzzification. Fuzzy logic is used to choose the best path between two nodes in a multipath network.

T. Dynamic Weight Adjustment for Weighted Clustering Algorithm

In [21], the authors proposed a dynamic weight adjustment by using soft computing such as fuzzy logic and neural networks. The weighing factors in the proposed algorithm change as the node dynamics change in the network. The crisp output for node dynamics becomes the input for the weighing factors to adjust accordingly. This algorithm selects the best cluster head by choosing the suitable weights for mobile nodes, with less computational overhead. In this algorithm, fuzzy model and weight correction model are used so that weights on the nodes can vary and help to extend the network lifetime.

U. Improved Algorithm based on WCA (IWCA)

In [22], the authors proposed an improved algorithm of WCA (IWCA) to limit number of cluster members, optimize the load of CH, and improve the performance. The proposed algorithm shares the self-adaptability feature of WCA and can adjust corresponding parameters according to different network characteristics to produce more stable clusters. The authors used average neighbour distance and relative speed of neighbour node to effectively reflect the communication between nodes.

V. Cluster Based Route Discovery Algorithm for AODV

In [23], the authors presented a cluster based route discovery algorithm for AODV routing protocol to address of high control overhead issue in the existing algorithms. They proposed this algorithm using a new concept of new node table, which is known as history table. This table is used to store the route history of previous transmissions to the destination to conserve the limited resources available. CHs are associated with this table and they check for the route history.

W. Node Connectivity, Energy and Bandwidth Aware Clustering Routing Algorithm (ENB)

In [24], the authors proposed to design a node connectivity, energy and bandwidth aware clustering routing algorithm to solve the issue of increased energy consumption and delay in the network. In this algorithm, CH is selected based on the combination of residual energy (E), node connectivity (N), and available bandwidth (B) using the ENB algorithm. Multimedia traffic splits into multiple sub-streams using the Top-N rule selection approach, where the data is split depending on the hit ratio. Shortest path multicast tree is established to send data to receivers using the proposed algorithm.

X. Node Performance Based Clustering Algorithm

In [25], the authors aimed at tackling security issues in MANETs by proposing a clustering algorithm based on node performance. In the proposed algorithm, CH is selected using a threshold of performance. Nodes with the highest resources and least mobility are chosen as the CHs. Metrics such as residual energy, free memory, processor speed, disk space, and node density are used to calculate the performance of a node. The authors used multi-criteria decision analysis to determine the weight associated with each metric. Each node calculates its own performance using the metrics and send it to the neighbouring nodes.

Y. Clustering Based Energy Efficient Algorithm Using Max-Heap Tree

In [26], the authors proposed an energy efficient clustering protocol that builds clusters using max-heap tree. In this protocol, Lowest ID Clustering (LIC) is used and nodes with higher energy is elected as CHs or the root of max-heap tree. The nodes within a cluster form a tree and the root is the CH with the highest energy. For inter-cluster communication, OLSR protocol is used with multi point relay (MPR) choosing the CH through which the data is to be forwarded. The implementation of this proposed protocol includes formation of cluster, selection of CH, intra-cluster communication, and inter-cluster communication.

Z. Core Gateway Relay Routing (CG2R) Protocol

In [27], the authors proposed a novel hybrid routing algorithm known as Core Gateway Relay Routing (CG2R) protocol, where the network is divided into zones. Each zone has one or more core gateway(s) which is significantly distinct from normal gateways in that core gateway manages more nodes than normal gateway. The proposed protocol aims to minimize the chances of a node moving out the zone. In CG2R, a node determines whether it is a core gateway node using the algorithm proposed by the authors. If there are two core gateways, the node with higher residual energy will be chosen.

AA. Dynamic Channel Allocation and Cooperative Load Balancing Routing Protocol

In [28], the authors proposed a dynamic channel allocation scheme and cooperative load balancing technique to address the issues of bandwidth efficiency. To increase the bandwidth efficiency, channel coordinators assign channel to the nodes for data transmissions. In the case of uniform load distribution, spatial reuse concept is used to improve bandwidth efficiency. In case of non-uniform load distribution, CDCA TRACE is proposed which is a combination of CDA-TRACE and cooperative load balancing. Clusters are formed using Partitioning Around Medoids (PAM) algorithm. Both PAM and CDCA TRACE improve channel access and load distribution in a heavy and non-uniform load distributed network.

BB. Energy Efficient Hybrid Routing Protocol (EE-HRP)

In [29], the authors aimed to enhance ZRP protocol by adding energy constraints in the protocol. They designed a Zone Head Selection Algorithm (ZHSA) to divide the network into zones and select a zone head (ZH) that has the maximum residual energy. In order to do this, they used max-heap tree to select the node with the highest residual energy as a ZH. Then, each node in the network is monitored using Node Energy Monitoring Algorithm (NEMA) for residual power periodically and be assigned different tasks based on their residual power. If the residual power of current ZH is below the threshold value, the node next in the max-heap tree with maximum energy is selected as the ZH.

CC. Balanced Clustering Algorithm using Extended Weekly Connected Dominated Sets (EWCDS)

In [30], the authors addressed the issue of non-uniform load distribution by proposing a new balanced clustering algorithm using ECWDS which enables two-hop communication in the network. The proposed algorithm consists of cluster formation, CH election, and route exploration phases. EWCDS is implemented to ensure data transmission is more efficient. Cooperative communication is achieved using EWCDS to handle various load distribution and to maintain the battery power levels of the nodes. Route cluster is used to gather the information from various nodes.

DD. Strength Based Energy Efficient Algorithmic Approach (SEEA)

In [31], the authors targeted at minimizing the energy consumption and conserving the battery power of the nodes. To do this, they proposed SEEA to calculate the node energy and divide the tasks according to the remaining energy to improve the performance of the network. Node with the highest energy is chosen as CH and paths are found with minimum weight. The proposed algorithm increases the network lifetime by distributing the power dissipation load evenly among the mobile nodes. Nodes with higher power perform data fusion and transmission while nodes with lower power perform data sensing. A mobile sink is also proposed in this algorithm which forward data to the BS in order to maintain the link.

EE. Cluster Head Selection Algorithm Based on QoS constraints (MAODV-HSBQ)

In [32], the authors aimed at improving the cluster head selection algorithm in MAODV multicast routing protocol by using QoS mechanism to reduce the randomness of the CH node selection while considering the network delay and bandwidth constraints. The improved algorithm is known as MAODV-HSBQ. To improve the CH selection, QoS is introduced, and delay and bandwidth are used as restriction. An optimal multicast group node with the lowest cluster cost is chosen as CH in this algorithm.

FF. Dynamic Node Recovery Technique and Genetic Algorithm (GA)

In [33], the authors compared the proposed dynamic node recovery technique with an existing protocol to improve the node recovery time in the network. The proposed work ensures successful retrieval of checkpoints in cases of node failures which reduces the recovery time. CH is elected based on trust factor, energy of the node and number of unsuccessful transmissions which should be low. Each node maintains count variable which is kept track of for checkpointing tasks. Checkpointing is done if the count value surpasses the threshold value. Genetic algorithm is used to find the optimal recovery path between the recovery node and checkpointing node for reliable data transmission.

Based on Table 1, different routing techniques and metrics were used in each protocol. The proposed protocols were classified as inter-cluster, intra-cluster and hybrid. Most of the routing protocols did not consider high mobility in a mobile cluster based sensor network. Hence, employing a routing protocol with a low or moderate mobility consideration in highly mobile networks is not suitable because nodes with higher mobility consume higher energy than nodes in other sensor networks. Due to the resource constraints, it is important that traffic load is evenly distributed among the nodes. Therefore, an efficient routing protocol is needed for highly mobile networks in order to balance the traffic load distribution and energy consumption throughout the entire network.

IV. CONCLUSION

This paper presents a survey on the state-of-the-art clustering routing protocols in MASNET. We present the findings in a comparison table which highlights the techniques and advantages as well as the disadvantages of each routing protocols discussed. To determine the efficiency of routing protocols, parameters such as energy efficiency, throughput, end-to-end delay, and packet delivery ratio are significant as these parameters reflect the effectiveness of the protocols in extending the network lifetime. In MASNETs, it is essential to balance the load distribution in order to improve the performance. Load balancing in mobile sensor networks is able to increase throughput and minimize network energy consumption which indirectly can enhance the network lifetime. On the basis of comparison between different cluster based routing protocols, it is clear that these routing protocols are useful in performance enhancement of MASNET. This paper will be useful for the researchers that are interested in the development, modification and optimization of routing algorithms for MASNET.

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Table 1
Comparison of Cluster Based Routing Protocols

Protocol	Cluster Communication	Technique	Baseline Protocol	Simulation metrics	Simulator	Benefits	Limitations
VLWBC	Inter-cluster	CH election	LEACH WCA MWCA	Cluster lifetime Consumed energy No. of clustering	NS-2.34	• improved network stability • increased cluster lifetime • lower energy consumption & higher availability	• don't consider node density and higher mobility in the network
CDCA-TRACE	Inter-cluster	Load balance	DCA-TRACE CMH-TRACE MH-TRACE IEEE 802.15.4 IEEE 802.11	Throughput Energy consumption IPDV	NS-2	• increases service levels and throughput • reduces average energy consumption and average absolute IPDV	• effects of upper layers such as the routing layer were not investigated using this algorithm • suitable only for clustered networks with heavy and randomly distributed loads
New Clustering Scheme	Inter-cluster	Load balance	WCA, GA, SA	CH duration CH communication	Not specified	• lower communication workload • longer duration for cluster heads	• entire network is re-clustered implying overhead
EECRP	Inter-cluster	Network coding	CBRP	Energy consumption	NS-2	• reduce the number of transmissions and the energy consumption • improves network lifetime	• EECRP in other cluster based routing protocols have not been studied • the effect of EECRP in different topologies and environment have not been studied, thus can't verify the performance of EECRP
GBDEER	Inter-cluster	Energy efficient path	Not specified	Not specified	Not specified	• avoids network partition • reduce energy consumption in route discovery and maintenance • (theoretically, not proven yet)	• theoretical for now • GBDEER is not implemented and tested
New Cluster Based Broadcast Algorithm with DCB	Inter-cluster	Broadcasting	Cluster based routing protocols without DCB	PDR Energy	NS-2	• high packet delivery ratio • lower energy consumption • increases the lifetime of the routes • decreases the amount of routing control overheads	• distance of the base station to each cluster head can easily affect the power level of CHs
Intra-cluster Routing Protocol with Back-up Path	Intra-cluster	Routing discovery	LEACH EARCBSN	Energy dissipation Lifetime awareness Throughput Avg. packet delay Connectivity rate	Calculation tool	• more energy efficient • better lifetime awareness • higher throughput • lower average end-to-end delay	• CN may not always present in all types of mobile sensor networks • collection and dissemination of information for every round can potentially drain the power of the nodes
VELCT	Hybrid	Data collection	CIDT MBC CTGDA CREEC EEDCP-TB	PDR Throughput Total energy Delay	NS-2	• offers minimum load on intra and inter cluster communications • avoids unwanted control packet flooding on node mobility • better PDR and throughput • lower energy consumption • minimum delay than baseline protocols • more stable links	• new DCN is selected every time new CH is elected • CH is elected every round
RCBRP	Hybrid	Routing discovery	AODV	Throughput Routing overhead PDR Avg. end-to-end delay	NS-2.3	• enhanced throughput and PDR • reduced routing overhead and average end-to-end delay	• values of the parameters measured using RCBRP are inconsistent • PDR of RCBRP decreases rapidly as number of nodes increases • average end-to-end delay of RCBRP is almost similar to those of AODV
PMRP	Hybrid	Routing discovery	AODV	Throughput PD fraction Normalized routing load Average end-to-end delay Energy consumption	NS-2.35	• better results in terms of throughput, PDR, routing load, average end-to-end delay, and energy consumption	• PMRP is found to initially produce higher energy consumption than AODV • does not guarantee the efficiency of this algorithm in mobile networks • re-clustering is done every time a CH dies • cluster reconfigurations are done all over again which consumes more energy of the network
LRPH	Hybrid	Loose-virtual coupling between nodes	LRPH-B MC DSR	Throughput PDR End-to-end delay Normalized overhead Energy consumption per received packet (ECRP)	OPNET Modeler 10.0	• better and higher throughput • higher PDR • lower end-to-end delay • decreased normalized overhead • decreased ECRP • results are also backed by real world implementation for PDR and overhead where static and mobile environments are considered	• only suitable for networks with high power and large transmission range mobile nodes
CAREDR	Inter-cluster	CH selection based on residual energy difference ratio	LEACH ACE-C	Throughput Energy consumption Network lifetime	NS2	• higher throughput • lower energy consumption • longer network lifetime	• node movement is assumed not to cause too much changes in network topology • energy consumption of CAREDR is almost similar to that of LEACH
EEQR	Inter-cluster	Prioritization of data and data collection	Static and mobile sink strategies	Average energy per packet Network lifetime Throughput Average delay per packet Packet loss ratio Coverage lifetime	OMNet++	• average energy per packet of EEQR is less • longer network lifetime • higher throughput • lower average delay per packet, suggesting that EEQR is scalable • lower packet loss ratio • better network coverage lifetime • use of super nodes as local sinks improves energy consumption	• only the sink is considered to be mobile; the rest of the network is assumed to be fixed
SALMA	Hybrid	Categorizing nodes into different states which allows the nodes to function differently in order to reduce the activity load	DSR OLSR ZRP HOPNET LEACH PEGASIS	End-to-end delay Routing overhead Energy consumption Average consumed power Number of dead nodes (performance of protocols)	NS2.35	• less average delay times • moderate values of overhead • better energy consumption • nodes consume less energy in SALMA • lower number of dead nodes at different rounds • does not put routing burden on non-transmitting nodes to reduce energy consumption	• all nodes continuously change their status which consumes more energy • the effect of mobility speed of nodes is unknown

Protocol	Cluster Communication	Technique	Baseline Protocol	Simulation metrics	Simulator	Benefits	Limitations
MSE	Inter-cluster	Mobile sink is introduced with a predetermined trajectory for movement; CH selects shortest path to sink	LEACH SEP	Energy consumption Network lifetime Influence of sink node locations on alive nodes	MATLAB	• lower energy consumption; almost linear consumption for almost 500 rounds • longer network lifetime • higher number of packets for almost 5000 rounds	• all sensor nodes are assumed to be fixed in position; only the sink is assumed mobile • the predetermined trajectory is static; topology change will cause the fixed trajectory to be unsuitable • only one mobile sink is considered; not suitable for large sensor networks
SKCA	Inter-cluster	CH election	KCMM	Average number of clusters Number of role changes Number of member cluster changes Average cluster lifetime Routing overhead Packet delivery ratio	NS2	• reduced number of cluster number • better performance in terms of role changes • higher average lifetime of clusters • lower routing overhead • higher packet delivery ratio • offers reduced and stable cluster topology	• the impacts of other parameters, e.g. mobility, density, and data traffic on the algorithm are not studied
Weight based energy aware hierarchical clustering	Inter-cluster	CH election	Mobility based protocol Weight based protocol EPAC	Throughput Node lifetime Energy remaining Mobility vs packet drop Clustering vs speed	Not specified	• better throughput • longer lifetime of node • less packet drops • better energy usage	• the effect high node density is unknown
Fuzzy Logic-Based Clustering Algorithm	Inter-cluster	Super-CH election	LEACH	Node lifetime Network stability End-to-end delay Network lifetime	NS2.34	• longer node lifetime • better stability • lower end-to-end delay • longer network lifetime	• assumes only BS is mobile while the rest of the network is static
Optimal Weighted Clustering Algorithm	Inter-cluster	CH election; Fuzzy logic	WCA	Packet delivery ratio Load balancing Energy consumption	NS2.35 MATLAB	• solves the problem of malicious nodes • higher PDR	• performance of proposed algorithm isn't compared with other available cluster based routing algorithm
Dynamic Weight Adjustment	Inter-cluster	Weight correction; CH election	WCA	Stability of network lifetime	NS2.35	• better stability	• only one baseline protocol used for results • only performance metric is observed
IWCA	Inter-cluster	Weight adjustment	WCA	Average number of CH Number of node rejoining Node update times	NS3	• optimizes the load on CHs • better stability • reduced overhead	• only one baseline protocol used for results
Cluster Based Route Discovery for AODV	Hybrid	Route discovery	Not specified	Not specified	Not specified	• the use of history table will conserve resource usage in the network	• theoretical/conceptual for now
ENB	Inter-cluster	CH election; Shortest path	Not specified	Not specified	Not specified	• expected to reduce energy consumption and delay	• theoretical/conceptual for now
Node Performance Based Clustering Algorithm	Intra-cluster	CH election	Density based clustering algorithm	Average number of clusters built	NS2	• improved network stability	• each node has compute its performance which can increase energy consumption
Clustering Based Energy Efficient Algorithm using Max-Heap Tree	Hybrid	CH election; Max-heap tree	Not specified	Not specified	Not specified	• expected to minimize energy consumption • expected to maximize network lifetime	• theoretical/conceptual for now
CG2R	Hybrid	Core gateway election	AODV CGSR	Packet delivery ratio Average end-to-end delay Control overhead	NS2	• higher packet delivery ratio, shorter end-to-end delay, and less overhead	• mobility speed of nodes is not considered as high speed nodes can easily move away from zones
Dynamic Channel Allocation and Cooperative Load Balancing Routing	Inter-cluster	Channel access; Load balancing	Not specified	Energy consumption Average end-to-end delay Network lifetime	Not specified	• lower energy consumption and delay and higher network lifetime with PAM algorithm • maintains bandwidth efficiency	• suitable only for clustered networks with heavy and randomly distributed loads
EE-HRP	Hybrid	ZH election	LEACH	Residual energy of node Energy dissipation	OMNet++	• lower energy consumption of network	• periodically checking the residual energy of nodes can result in ZH losing its energy
EWCDS	Inter-cluster	Connected dominating sets	Not specified	Energy remaining Delay Packet delivery factor (PDF)	NS2	• higher energy remaining • lower delay • higher packet delivery ratio • can manage both battery power and non-uniform load distribution	• CHs are self-selected; no weights or IDs are used
SEEA	Inter-cluster	Energy efficiency	Energy Saving Ad Hoc Routing (ESAR)	Throughput Energy consumption PDR Network delay time Packet drop	NS2	• higher throughput • lower energy consumption • higher packet delivery ratio • average delay • less packet drops • longer network lifetime	• the impact of high node mobility on the protocol is unknown
MAODV-HSBQ	Inter-cluster	CH election	MAODV	Routing overhead PDR Average delay	NS2	• better packet delivery ratio • lower average delay	• slightly higher routing overhead
GA	Inter-cluster	Dynamic node recovery	DSR	Probability of recovery Residual energy	NS2	• higher probability of node recovery • higher residual energy • better network lifetime	• the impact of high node mobility on the protocol is unknown
WSEEC	Inter-cluster	CH election; Security	WCA	Network lifetime Energy consumption Throughput Delay Packet delivery ratio	NS2.35	• longer network lifetime • less energy consumption • lower delay • almost equal throughput with WCA	• PDR of WSEEC is lower than that of WCA