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Energy-Efficient Routing Protocol for Wireless Sensor Network: A Comparative Study

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Abstract

The modern and present-day developments are more focused on transmitting delicate information to the final destination. To fulfil this criterion, sensor nodes (SN) have been developed, which integrate various sensing and computing unit along with the power supply, the transceiver in one single unit. These sensor nodes combined to form a network called wireless sensor networks (WSNs). WSN have a vast application like industrial monitoring, forest fire detection, border protection and security, water quality monitoring and so on. The pre-existing research mainly focused on reducing energy consumption during the process of computing and transferring data to BS. Sensors in the various applications of WSNs establish remotely in large numbers and operate autonomously. Although clustering is an effective way to increase network lifetime by using energy efficiently. Unequal or heterogeneous clustering is used in which the size of the cluster varies according to the distance of BS. Keeping all these issues, in this paper we have classified various routing protocols for WSN with their methods, advantages and disadvantages which is helpful for the next generation of WSNs.

Keywords: *Wireless sensor network; Cluster head; Clustering algorithms; network architecture; lifetime*.

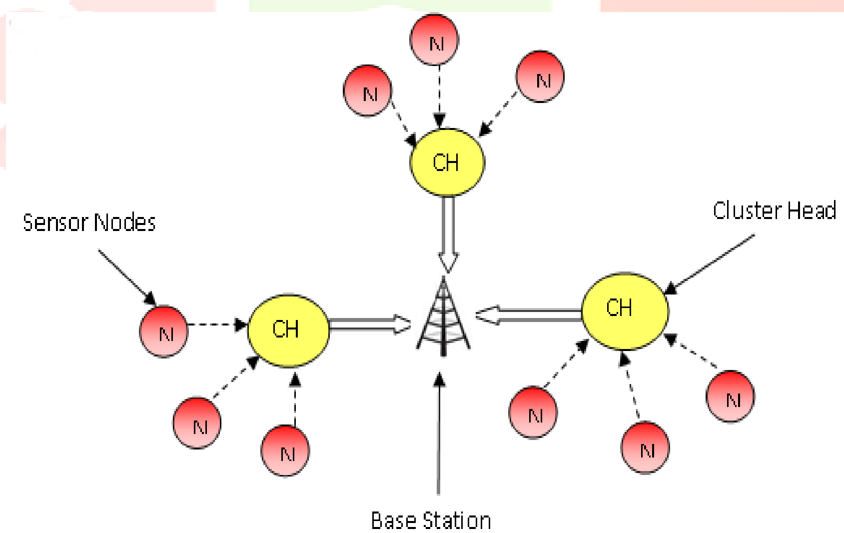
1. Introduction

A wireless sensor network (WSN) is made up of general sensor nodes and the sink node. The main functions of general sensor nodes include sensing environment and forwarding information to the sink node. As an indispensable part of the Internet of Things (IoT) system, WSNs have been widely used in diverse applications ranging from agriculture, industry, military and transportation. In real WSNs, low-cost general sensor nodes can only be allocated limited capacity. If a sensor node's load exceeds its capacity, it cannot continue to work normally. When a sensor node fails, the data ow originally passing through the failed sensor node will follow a new routing path to arrive at the sink node, which may make more sensor nodes fall into failure due to load spills and a new round of failure events might be triggered by these failed sensor nodes. We call this dynamic process caused by data rerouting, a cascading failure. Under the influence of cascading failure, a small number of sensor nodes fall into failure, which may result in the signi_cant decline of network connectivity. The sensing units are usually a combination of two sub-units as sensors and analog-to-digital converters (ADCs). ADC uses to convert analog to a digital signal for the base station to understand activity The processing unit, usually paired with a tiny storage unit, controls the events which cause the sensor node to interact with other nodes to perform the sensing tasks assigned. A node is connected to a network by a transceiver and the sensor messages are received using this transceiver. The power unit is one of the most critical elements of a sensor node, which is very useful to sensors without this sensor can't work anywhere under any environmental condition. The deployment of sensor nodes can be deterministically or randomly in WSNs. In applications when the deployment region is physically accessible the use of deterministic methods are desirable. On the other hand, random deployment of sensor nodes is used when the deployment area is physically inaccessible, e.g., border area, Mines, underwater etc. WSN is mostly concerned with the life of a network that is affected directly or indirectly by network energy and we preserve the network's energy by arranging the sensors into groups, termed as clusters. Each cluster has a master node, often known as the cluster head and many other sensor nodes. The head of the cluster generally fuses and aggregates the other sensors. The network should have a decent amount of energy to last longer. The biggest challenge for WSN is the network's lifespan, which is controlled directly or indirectly by the energy of the network. For optimal usage of network energy clustering of the sensor nodes is implemented. Each cluster has a master node and multiple other sensor nodes as a network member. The lifetime of the network may be enhanced with the aid of such clusters. The energy of the network may be enhanced by increasing the number of sensors in the field because increasing the number of sensor nodes increases the energy supply of the network but costs are fairly high since the cost of using a sensor is 10 times more than the price of the batteries. Therefore, better and more economical to use some high-battery sensors to improve the network lifespan.

Figure 1: A architecture of Clustered based WSNs

The following are today's real-world types of WSNs used:

- Cloud WSN
- Underground WSN
- Under Water WSN
- Terrestrial WSN
- Multimedia WSN
- Mobile WSN



Several sensor nodes are spread throughout the networks in a geographical area. Every node of sensors has an Omni-directional, 360 -angle rotating antenna that transmits a message to all the sensor nodes in the data transmission range. These sensors are all organised into clusters to conserve energy and enhance the longevity of the network. Each cluster will be composed of one cluster head node (CH) and other sensor nodes will be component nodes.

1.1 Evaluation Matrices for WSN System

In a WSN, there are various parameters used to estimate the throughput of the network. Numerous parameters are as follows.

Network strength

Power consumption by a sensor node in a network is the main issue. To enlarge the lifetime of a WSN network, to manage the energy utilization in a network, the network should be designed such that the sensor node consumes the least energy and transfers more data. The sensor node is either identical or odd.

Scalability

Scalability is the property of a wireless system to handle the performance of a network by adding resources (sensor node) to the wireless network system. Suppose new nodes are added to the network, and then there will be no effect on any output of the network.

Temporal accuracy

The sensor nodes of WSN send the sensed information from time to time to the end-user to decide for betterment. Every operation performs within a specific time.

Coverage

Coverage in a wireless sensor network means to sense over the target region. This is a primary factor for ensuring the eminence of examination provided by the WSNs or in another way we can say that all sensor nodes are dispersed in the whole region to be observed.

Response time

Any type of wireless sensor network-based application, an application that has a good response time for fire detection scenario response time should be fast with respect to the sensor node. If the sensor node is in the active mode they provide the information quickly when the fire is found.

Security

Security is an important factor of the wireless sensor network. Threats do not allow entering into the application and disturbed the application process a sensor node deployed in a remote or hostile environment and perform their task in an unattended manner.WSN applications prevent the attack from outside and secure the privacy of collected data.

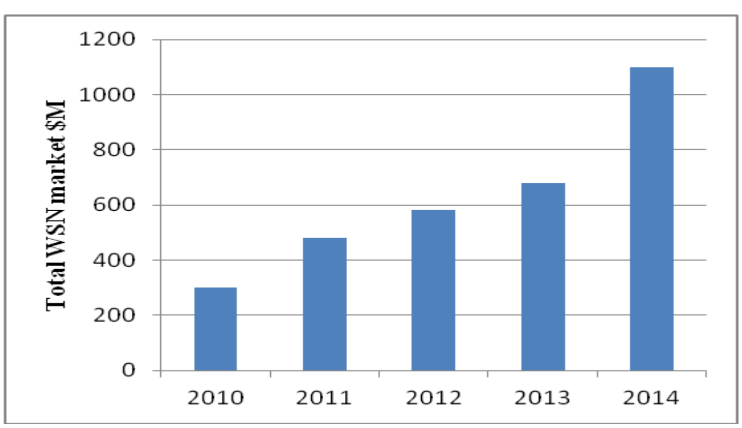


Figure 3: WSN market 2010-2014 ($ Millions)[14]

1.2 Limitations of WSNs

The environment of WSN has a limitation, listed as follows:-

a) Negative devices provide low energy.
b) Operates in short communication range – consumes an amount of power.
c) Possess modest processing power-8MHz.
d) Possess very little storage capacity – a few hundred kilobytes.
e) Have batteries for a limited lifetime.
f) Requires minimums energy – constrains the protocols.

2. Clustering and CHs Election

Clustering is one of the energy maximize techniques used to increase network lifespan in WSN. These include grouping device nodes for clusters and choosing CHs for all clusters. Cluster heads collect the information that is sent by the sensor node, and then the cloister head chooses the shortest route to pass the collected information to the sink. Clustering and choosing a cluster head are both very important approaches that can be used to increase the lifetime of the WSN.

2.1 Cluster Component

There are various important cluster components are listed as follows:

- Cluster head (CH).
- Gateway node.
- Cluster member.
- Cross-cluster link.
- Intra-cluster link.

2.2 Cluster Head

CH plays a significant role to broadcast the message to sink and they also do data fusion and data aggregation. Apart from CH, all node acts as a non-CH or cluster member. The main challenge in WSNs is to elect the cluster heads based on some input parameters some common parameters used to elect the CHs are as follows:

- Remaining energy.
- The number of neighbours nodes.
- Farness from sink to nodes.

2.3 Clustering Objectives

In the cluster technique, there are some objectives listed as follows [15]

- Aggregations allow.
- Limits data transmission.
- Enhanced network lifetime.
- Diminish network traffic.
- Data fusion takes place in cluster heads.
- Minimize coverage problem

2.4 Advantages of Clustering

- Scalability
- Data aggregation
- Fewer loads
- Minimization of energy utilization
- Minimize the Collision between sensor nodes.
- Load Balancing
- To avoid Fault tolerance
- Improve the QoS

3. Individual Node Evaluation Metrics

A node is assessed based on its distinct perimeters. Different responsibilities such as the leaf node, the cluster head node, the associated node etc may be given to each node based on those perimeters. Figure 2 shows the fundamental components of a sensor node[3].

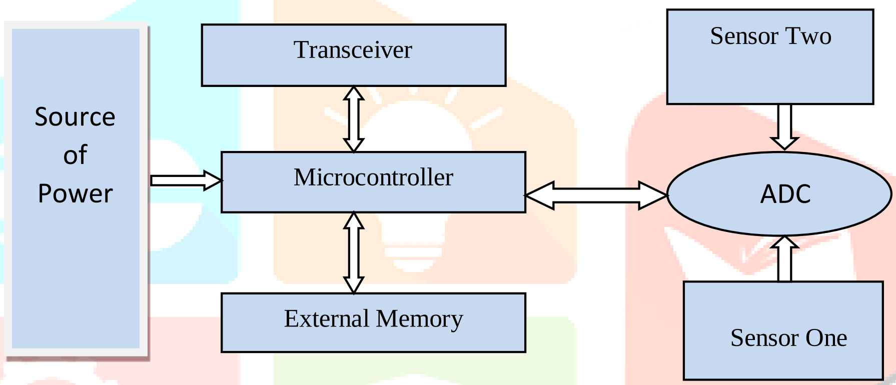


Figure 2: Fundamental Component of Sensing Node

The node perimeters can be indicated in the following manner:

- Robustness
- Size and cost
- Flexibility
- Computation
- Communication
- Security

Robustness: Every node needs to be as resilient in trying to attain maximum lifetime requirements. Since a node is constantly required for years to operate, individual failures should be able to be tolerated.

Size and Cost: The Size and the cost of the equipment have a big influence on ease and cost of deployment. The node's physical size also affects the overall node deployment.

Flexibility: There must be a flexible and adaptable node architecture. There are a variety of applications a node must be able to adapt to.

Computation: The node's CPU must be able to quickly decode and calculate data arriving to speed up communication between the nodes.

Communication: Communication is the key assessment parameter for the node. The node should have a broad communication range which can eventually improve the performance.

Security: A node should be able to handle, process and authenticate encryption operations at the individual level.

4. Advantages of Clustering

- Data aggregation
- Scalability
- Fault tolerance
- Load Balancing
- Collision Avoidance
- Reduced energy consumption
- Fewer loads
- QoS

Data aggregation: Aggregation of data helps to reduce duplicated data collected from members' nodes.

Scalability: Because the node is organized into several assignment levels, adding more nodes to the cluster is straightforward.

Fault tolerance: Every time a node suffers from the depletion of energy, it is reclustered.

Load Balancing: Equal clusters adjust the extension of the network by balancing the load and prevent premature exhaustion of energy.

Collision Avoidance: By distributing resources to each cluster orthogonally, the data may be sent without collisions.

Less energy: If just non-redundant and aggregated information is to be sent, energy is utilised less.

Fewer loads: Aggregated data prevents the transfer of data from CH to BS from being loaded.

QoS: Clustering helps in providing the end-user with quality and non-redundant data.

5. Designing challenges of clustering:

The implementation of WSN networks becomes increasingly difficult. Compared to cable networks, the design objectives of the WSN are more targeted. To extend the life of the network, the WSN is split into groups called clusters. In the design of the clustering algorithms, several design factors are described in [5].

- Communication
- Security
- Storage
- Network Lifetime
- Limited energy
- QoS

Communication: Communication over the whole area may enhance dependability and also provide network coverage to achieve the correct results.

Security: WSN is very susceptible to security and threats. Security considerations must therefore be incorporated into the design of clustering protocols.

Storage: The storage space in sensors is quite low and so the storage and query requirements must be met.

Network Lifetime: The limited energy might cause network life to be reduced. By introducing intra-cluster communication and multi-hop routing techniques, clustering can minimize energy consumption.

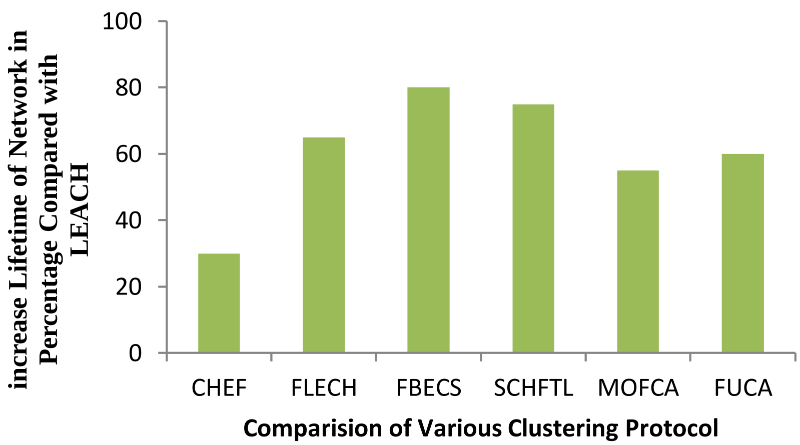
Limited Energy: Energy is very restricted in the sensor networks. Compared to direct transmission, clustering can minimize energy usage.

QoS: Clustering focuses constantly on energy efficiency but does not focus on quality. This is why quality in the clustering algorithm should always be provided.

6. Comparison

In this section, we compare various fuzzy logic-based clustering algorithms. The first graph showed the network lifetime enhancement of the latest cluster-based protocol in Figure 7. Here LEACH is a traditional protocol which is very useful to improve the lifespan of the WSN, apart from LEACH we have to consider the latest protocol which is more useful as compared to LEACH for wireless sensor network.

Figure 7. Lifetime in percentage as compared to LEACH



The performance of the clustering process relying on the fuzzy logic input parameter. Various approaches are used in MATLAB to assess the performance. Table 3 lists the simulation parameters. The comparison analysis is shown in figures 9 & 10, respectively for the first node dies (FND), the quarter node dies (QND) and the last node dies (LND). In this review when the first node dies to start, the network stability period decreases. Figures 9 and 10 shows that the FBECS protocol outperforms all the latest energy-efficient protocols, then SCHFTL, etc.

Table 2. Comparative study of fuzzy-based clustering technique

Techniques	Network type	Method of Clustering	CH Selection	Parameter of CH Selection	Communication Based on Intercluster
CHEF (Kim et al., 2008) [6]	Homogenous	Distributed	Random	• Energy • Local distance	Direct communication
LEACH-FL (Ran et al., 2010)[21]	Homogenous	Centralized	Determine by Sink	• Node energy • Density • Distance from Sink	Multi-hop communication
CEFM (Jin et al., 2011) [50]	Homogenous	Distributed	Determine by Sink	• Energy • Rate of retransmission • Number of neighbours • Location	Direct communication
CHEATS (Pires et al., 2011) [41]	Homogenous	Distributed	Random	• Remaining energy • Distance from Sink	Direct communication
FLCEP (Mhemed et al., 2012)[28]	Homogenous	Distributed	Random	• Energy level • farness between Sink and CH • farness between the nodes and CH	Direct communication
IFCU (Mao et al., 2012) [52]	Homogenous	Distributed	Random	• Energy level • Distance to Sink • Local density	Multi-hop communication
HFCP (Mohan et al., 2013)[53]	Heterogeneous	Distributed	Random	• Residual energy • Predicted residual energy	Direct communication
SCCH (Izadi et al., 2015)[30]	Homogenous	Distributed	Random	• Node density • Node Centrality • Energy	Direct communication
MCFL(Mirzaie et al.,2017)[54]	Homogenous	Distributed	Determine by Sink	• Remaining energy • The number of neighbours of each node.	Multi-hop communication
EEDCF (Zhang et al.,2017)[55]	Homogenous	Distributed	Random	• Residual energy. • Node degree • Neighbour node • Average remaining energy.	Direct communication
FHRP(Neamatollahi et al.,2017)[56]	Homogenous	Distributed	Random	• Remaining energy • farness from the sink	Multi-hop communication
FUCA(Agrawal et al.,2017)[48]	Homogenous	Distributed	Determine by Sink	• Remaining energy • Node density • farness to Sink • Competition Radius	Direct communication
FLECH (Balakrishnan et al.,2017)[44]	Homogenous	Distributed	Determine by Sink	• Remaining energy • Node centrality • farness to Sink	Direct communication

FLEEC (Wang et al.,2018)[57]	Homogenous	Distributed	Determine by Sink	• Node density, • Distance-to-Sink, • Total-Distance • Residual-Energy	Direct communication
SCHFTL (Ayati et al.,2018)[60]	Homogenous	Distributed	Determine by Sink	• Remnant Energy • Centrality • Communication quality • Dos attack • Total Delay • Distance from Sink	Multi-hop communication
E-CAFL (Mehra et al.,2019)[46]	Homogenous	Distributed	Determine by Sink	• Remaining Energy • Closeness to Sink • Density	Direct communication

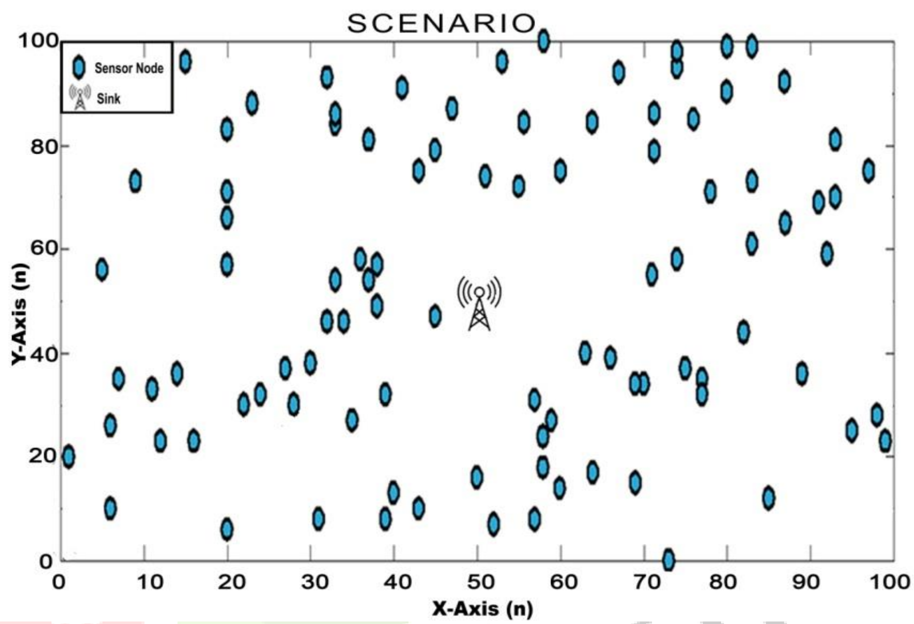
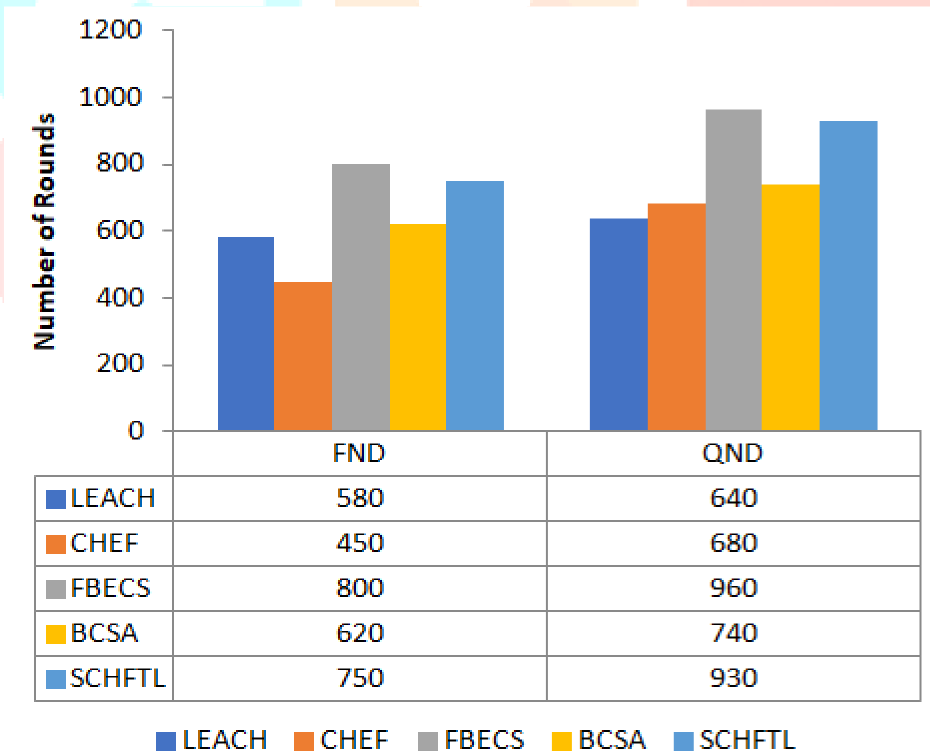


Figure 8: Common network scenario for WSNs.

Table 3. Common Simulation parameters

Parameter	**Value**
Field	(100m X 100m)
Sink Location	(50,50)
Free space amplification factor $\mathcal{E}_{fs}$	10 $x10^{-12}$ J/bit/m^2
Initial Energy	0.5J
n (Number of nodes/motes)	100,200
Multipath amplification factor $\mathcal{E}_{mp}$	0.0013 $x10^{-12}$ J/bit/m^4
Deployment	Random
Select	50nJ
E_{DA}	5nJ
Packet length	4000 byte
Header	200 byte



	FND	QND
LEACH	580	640
CHEF	450	680
FBECS	800	960
BCSA	620	740
SCHFTL	750	930

Figure 9. Comparison of the various protocol in terms of the First node dies (FND), Quarter node dies (QND), Half node dies (HND) for N=100.

7. Conclusion

WSN is demanding independent topology management and energy-saving measures because of restricted supplies and accessibility. Several energy conservation techniques have been provided, but the two-layer hierarchy structure and the distribution of several control functions, including energy efficiency, non-variance and several goals, are some of the most well known and satisfactory solutions. The failure and topology control is controlled by numerous sensor nodes. Fuzzy logic is used to improve the performance of a clustering method, however, the main difficulty is that it requires foundational knowledge to create a rule for membership functions. Algorithms with various membership functions can provide different results with the same ruleset. The fundamental difference between the different techniques is that the sensor node's probability value is calculated using various input parameters. Choosing a system that is more efficient, less complicated and more reliable is a big issue since sensor networks are applied when preferences are different from network objectives such that information fidelity is a greater priority than higher fuzzy systems. Researchers have intensively examined fuzzy-based clustering in different domains and certain elements have yet to be adequately studied. Some areas of research, such as the use of network layer spatial correlations to minimize the number of bits sent using the furry logic, the maximum number of fuzzy input variables, and the neural networks inside WSN, need additional investigation. A lot of data and tables from the last 10 years' articles have been reported and discussed in depth in this review study. For researchers and independent organizations, which are working to build a real-time application, this review article will become highly useful in the future.