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Survey on fault tolerance-based clustering evolution in WSN

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Abstract: On-going research on remote communication and sensing essentially made accessible the flexible technology called 'wireless sensor network (WSN)', which is independent, self-organising and self-healing in nature. The WSN comprises an extensive number of homogeneous or heterogeneous sensor nodes that may be deployed in a uniform or non-uniform manner in a targeted zone. The organisation of WSN can be stretched out from residential to a harsh and hostile environment. The manageability of WSN is very subjective to an efficient adaptation to the failure situations. In this line of thought, clustering has been proven as an efficient strategy for prolonging the sensor network lifetime and selecting the correct topological structure for the sensor network. The authors' first present a survey of existing survey works from 2002 to 2019 and then present a tutorial on existing fault-tolerant protocols with a comparative analysis. The target audience of this work is novice researchers in the field of WSN to get a preliminary idea about clustering and its objective.

1 Introduction

Human developments are always open to some sort of faults [1, 2]. All these advancements in the field of communication such as wireless sensor network (WSN), internet of things, embedded system, *ad hoc* networking, and so forth are the products of human insights. Here, human insights tend to the mind-set of accessing the comfortability in lifestyle such as smart home, smart transportation, remote communication etc. Presently, WSN is one of the widely accepted tools for sensing and controlling the applications from the remote end. Despite wide acceptance, the architectural constraint frequently invites various types of faults at several stages of the WSN life cycle. Energy is the backbone strength of any network, which acts as a driving force for the system to execute a task. Among the several challenges of WSN [3], efficient energy consumption is gaining significant attention from researchers explicitly when the dense number of sensor nodes (SNs) is deployed in a remote and hostile environment. The major problems which can occur in association with energy are rapid energy depletion by a particular SN, replacement, or recharging of the battery, providing power back up, dealing with energy hole etc. [4]. Furthermore, the various operations performed in WSN such as transmission process, clustering, cluster head (CH) selection, and routing all of these demands a substantial investment of energy which leads to a decrease in the power level of SNs [5].

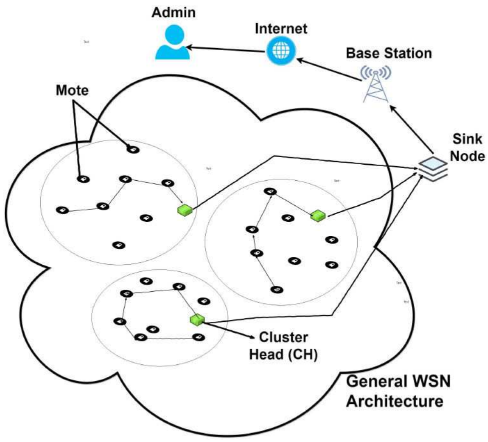

Fig. 1 *Architecture of WSN*

Fig. 1 illustrates the conventional architecture of WSN. The WSN architecture consists of mote or SN, CH, a sink node, and base station (BS), where all these are connected over the wireless medium. The final objective of WSN architecture is to transmit the collected data to the admin for generating meaningful information. The objective of this work is to study the motion of clustering in WSN over the time-series. The very beginning of clustering methodology is a hierarchical pattern but over time, the clustering approaches evolved rapidly as per the demands of advance WSN-based applications. The search result on clustering reflects that there are hundreds of clustering approaches proposed in the literature. Here, we have picked a few selected clustering approaches where we have noticed the variation in clustering schemes. We have named that variation as an evolution of clustering in WSN, which reflects the time-wise changes in the clustering approaches. This study gives brief insights about the various clustering methodologies in WSN with few examples under each evolutionary category.

1.1 Fault in WSN

Here, we provide a brief insight on fault in WSN as the fault is very closely associated with the clustering approach. The cause of the close association is the remotely deployed sensor networks (SeNs) mostly constraints with energy, memory, and computational capacity, which invites frequent fault in WSN. According to our study, we found that so far no such clustering algorithm has been proposed, which can handle these two major issues at a time. These issues are the selection of efficient CH based on cluster member (CM) population and efficient pattern of SN distribution [6]. The existing algorithms mainly deal with three primary issues such as quick energy dissipation, inefficient routing, and frequent involvement of CM in the cluster formation process.

The idea of fault tolerance evolved at the beginning of the 1950s. Prof. Antoine Svoboda is the first researcher who structured the first fault-tolerant computer 'SAPO' [7]. He modelled it by using a magnetic drum memory and relays. The processor has utilised two factors such as triplication & voting scheme triple-mode redundancy (TMR) and the error-prone memory with automatic retry in case of fault occurrence. The same group builds

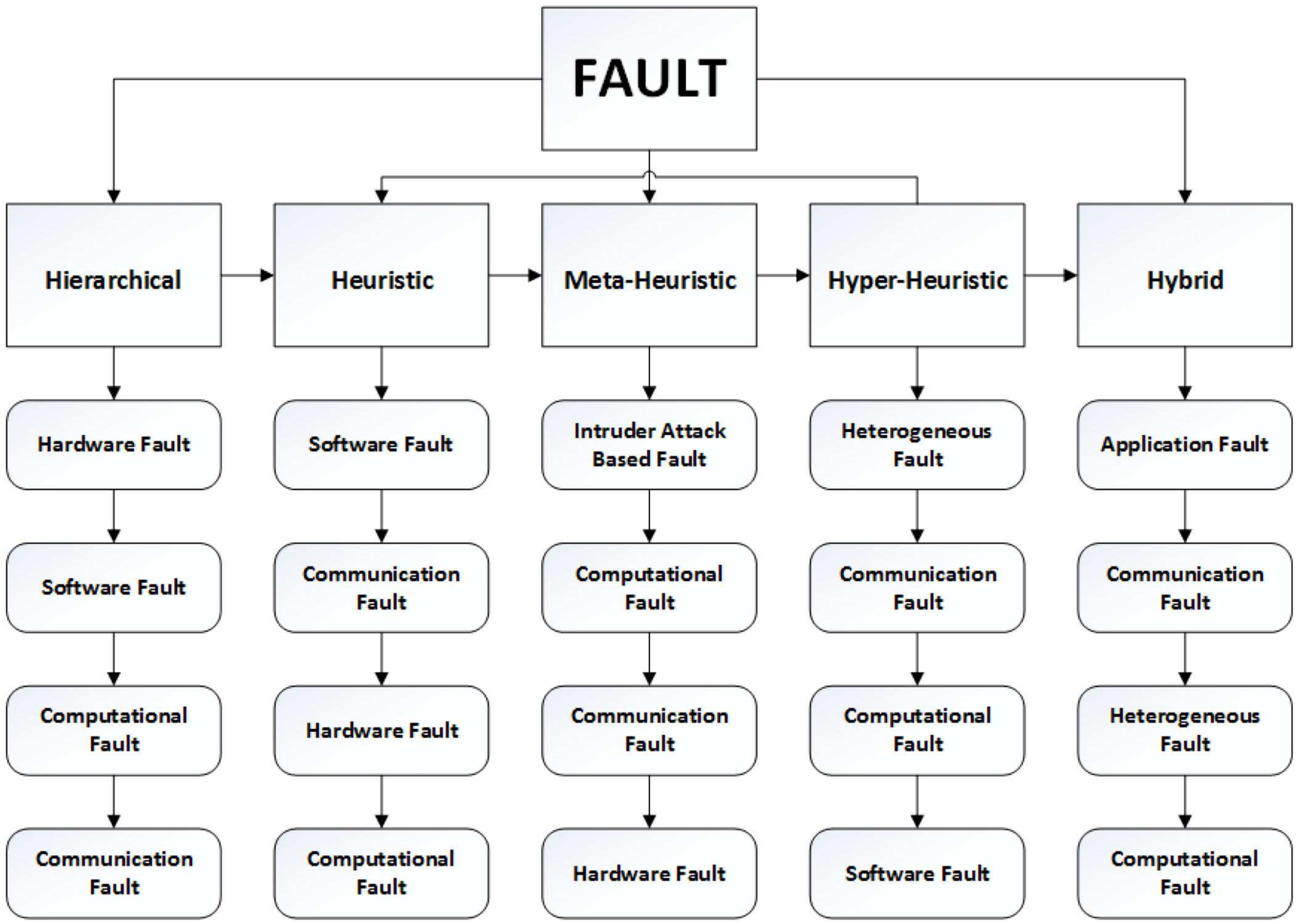

Fig. 2 *Preference of clustering approach based on fault nature*

the second machine called 'EPOS', which additionally contains the complete features of the fault-tolerance process. In 70 years, various fault-tolerant frameworks have been produced and eventually, they segregated into three distinct classes: (i) long-life (e.g. 'NASA' space probes), (ii) ultra-trustworthy (e.g. nuclear plant), and (iii) high-accessibility (e.g. supercomputers used by the bank). This field of research is gradually improving and gradually new fault-tolerant architectures have been introduced [8].

The harsh and hostile deployment of SNs always has a risk of SN malfunctioning, which introduces fault. Sometimes these faults lead the SeN towards a catastrophic situation. To deal with such faults a strong fault-tolerant mechanism is required. This state-of-the-art type essentially centres on fault counteractive action and adaptation to the failure process. There must and should be a proper healing mechanism for handling fault occurrence and to make the SeN robust and reliable for making a correct decision irrespective of fault presence or absence.

The nature of fault can be classified as persistent or sporadic in the case of both homogeneous and heterogeneous environments. The several causes for fault occurrence can be classified under three categories such as hardware fault, software fault, and communication fault. The factors that lead the SeN towards fault are residual energy (R_e) of the SN, traffic condition, link issues, localisation of SN, and topology of SeN. In our survey work, we focus on low R_e-based fault and its related fault-tolerant algorithms. The preferences of the clustering approach-based fault are illustrated in Fig. 2.

1.2 Sensor and its applications

The SeN comprises a limited number of untended, energy constraints, and low memory SNs, which is the miniature unit of the SeN. The sensor comprises various types of units such as sensing, management, transceiver, power, capacity, actuator, and localisation units. These SNs are communicating with each other over radio transmission in an omnidirectional manner. The hardware segments of the SN are a transceiver, small memory, a small-scale controller, and an omnidirectional antenna. Normally, the SNs are arbitrarily deployed in an application explicit topographical zone (e.g. sensors are dropped by the assistance of drone). SNs communicate with each other and collaborate as far as information detecting, handling, and transmission is concerned. The SNs are connected either directly or indirectly. The population of sensors typically dense in nature and this density of sensor arrangement prompt forming of clusters. The SNs are deployed in the objective of detecting and revealing of collected data to the dominating node called CH, further, the final aggregated information sent to the BS to create information out of data. Based on SNs' properties such as energy, data packet format, and computational power, the SeN can be of two types: homogeneous and heterogeneous. According to the application, the SNs can be deployed either static or mobile manner. Table 1 and Fig. 3 illustrate the various sensor-based applications.

The remote sensor deployment is a prime problem domain in light of its wide ramifications in the different fields beginning from science, geography, space, automobiles, and many more. The applications were WSNs have been implemented are rural automation, smart city [16], the front line in military application, industry mechanisation for automation, space, condition, interruption discovery system, climate estimating, building design, route exploration, social insurance observation, volcanic glitch, in vehicles, business etc. The domestic deployment of the WSN has been illustrated in Fig. 3. The various domestic applications were the sensor can be deployed are as follows: intelligent transportation, smart architecture, sports, smart environment monitoring, smart fuel station, smart supermarket, smart health care unit, smart water management, smart rural village etc.

Fig. 3 *Sensor application in domestic environment*

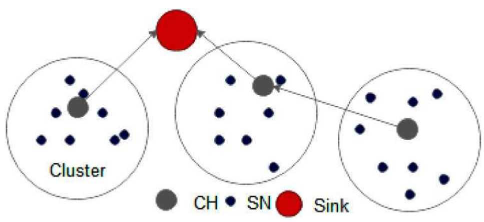

Fig. 4 *Communication within a cluster of WSNs*

Table 1 Application where sensor may deployable

Domains	Applications
home [9]	smart home, smart applications, automation, smart building and remote controlling
industry [10]	smart inventory management, production automation, safety measure, robotic supervision
health [11]	remote patient health monitoring, robotic operation
defence [12]	bomb detection, intruder alert, brain finger printing, detection of chemical and biological attack and drug management
environmental [13]	weather forecasting, precision agriculture, flood detection, water resource monitoring, emergency situation management, rain prediction etc.
habitat [14]	animal position detection, movement tracking
commerce [15]	stock exchange prediction, traffic management, parking solution, consumer and supplier gap management (business-to-business)

1.3 Clustering

Clustering is an unsupervised learning-based topology. It is an automatic process for grouping of the same type of object or SN,, which is called 'cluster'. There are many common factors, which are usually considered for clusterings, such as distance, link quality, energy level, application-specific traffic and timing, and other quality-of-service (QoS) measures. Each cluster has one CH as a dominating node, which is in charge of data collection & aggregation and transmission to the BS for report generation by the end-user. Based on the mode of communication, the SN may adopt direct (1-hop) or indirect (multi-hop) communication to interact with the BS. Direct communication with the BS consumes more energy in case of long-distance communication, which is why clustering is used to provide a multi-hop path that saves energy of the source node. Fig. 4 presents the clustering process in the WSN [17], where the SNs get clubbed based on any one of the above-mentioned factors. These clusters are monitored by a dominating node called CH. The CH aggregates the collected information from SNs and forwards that to the sink node.

The rest of the paper is segmented as follows: Section 2 covers a brief chronological review of 17 years (i.e. from 2002 to 2019) on well-known existing survey works; Section 3 contains a tutorial on 30 well-known clustering algorithms with an analysis report and Section 4 concludes the paper followed by references.

2 Survey of survey works

In this section, we present an extensive summary of well-known existing surveys from 2002 to 2019 (17 years) from the existing literature to understand the motion of clustering in WSN. Table 2 presents survey works from 2002 to 2012 and Table 3 presents existing works from 2013 to 2019. This section will help to understand the motion of clustering in WSN, explicitly for the researchers who are working in the survey on clustering in WSN. Additionally, the novice researcher will also able to understand the progression of fault tolerance through clustering with time-series. Tables 2 and 3 present the well-known survey papers, where their unique contributions have been discussed. These survey papers motivate us to survey the existing clustering algorithms of WSN evolutionarily.

3 Tutorial on evolution of clustering approaches

The dense deployment of SN and the demand for data in the aggregated format from the various corners of the acting field necessitates the need for efficient topology for the sake of load balancing and extending the network lifetime. The very common and effective approach for the proper organisation of SN and resource balancing is clustering. Clustering in WSN defines that the grouping of a set of SN based on selected factors and electing one node as CH for the data transmission process. The total

Table 2 Chronological presentation of existing survey works from 2002 to 2012

Year	Authors	Uniqueness of contribution
2002 [18]	Akyildiz *et al.*	depicts the idea of SeN. Investigated the detecting tasks and potential of SeN applications. Surveyed on elements which impact the structure of SeN. Exhibited, the communication architecture algorithms and protocols designed for each layer with open issues.
2005 [19]	Akkaya and Younis	presented fundamental ideas identified with the routing procedure with QoS protocols
2006 [20]	Nasser and Arboleda	discussed a proactive and responsive clustering environment for WSN
2006 [21]	Younis *et al.*	discussed the problem with the clustering strategy. Furthermore, analysed a couple of key issues that impact the on-going execution of clustering frameworks in sensor-based applications.
2006 [22]	Dechene *et al.*	discussed on the segregation of 12 protocols in terms of heuristics, hierarchical, weighted, and grid schemes
2007 [23]	Younis and Akkaya	presented and categorised the current momentum on the basis of static and dynamic placement in WSNs with the issues
2007 [24]	Moreira Sá de Souza *et al.*	presented a fault nature-based taxonomy and reviewed the various methods to deal with adaptation to fault tolerance and identification in WSNs in both logical and application-driven research studies
2007 [25]	Abbasi and Younis	reviewed different clustering protocols for WSNs, featuring their complexity, objectives, properties. Analysed the past clustering algorithms dependent on measurements, e.g. location-awareness, cluster stability, cluster overlapping, convergence rate, and support for node mobility.
2007 [26]	Paradis and Han	summarised and compared existing fault-tolerant methods related to sensor applications with research challenges
2007 [25]	Abbasi and Younis	proposed a novel taxonomy, surveyed the clustering conventions concerning variable delay time and consistent union time in WSNs
2008 [27]	Kumarawadu *et al.*	surveyed on the arrangement for cluster development, criteria for CH selection, key structural difficulties, and analysed the different execution issues related to WSN clustering
2008 [28]	Yick *et al.*	surveyed few new WSN-based applications. Classified the issues into three distinct classes. Explored the significant advancement and plot new challenges.
2008 [29]	Deosarkar *et al.*	discussed distributed CH choice techniques dependent on the order of the deterministic plan, versatile plan, and joined measurement conspire. Compared the expenses of CH determination as for cluster arrangement, conveyance of CHs, and production of clusters concern.
2009 [30]	Jiang *et al.*	introduced clustering plans of WSN dependent on eight clustering properties and analysed well-known WSN clustering algorithms
2009 [31]	Anastasi *et al.*	reviewed diverse energy-efficient clustering algorithms with multiple attributes for heterogeneous WSN
2009 [32]	Mamalis *et al.*	reviewed goals and design challenges of clustering in WSNs with probabilistic and non-probabilistic approaches
2009 [33]	Garcia Villalba *et al.*	explained characterisation and improvement techniques for routing optimisation techniques in WSN
2010 [34]	Bhuyan *et al.*	discussed difficulties for QoS support in WSNs with existing methodologies on routing protocols
2010 [35]	Bhuyan *et al.*	discussed the principal challenges for WSN clustering with various factors. Analysed prevalent clustering algorithms for WSNs.
2010 [36]	Katiyar *et al.*	discussed 12 clustering protocols
2011 [37]	Sheikhpour *et al.*	studied and compared diverse energy-efficient clustering protocols with different attributes for heterogeneous WSN
2011 [38]	Wei *et al.*	introduced characterisation of WSN dependent on three traits and discussed the difficulties in WSN clustering
2011 [39]	Joshi and Priya	shared of commonplace clustering routing in WSNs, compared few well-known WSN clustering routing protocols dependent on energy preservation and system lifetime
2011 [40]	Xu and Gao	investigated and compared well-known clustering routing protocols in WSNs
2011 [41]	Kumar *et al.*	discussed 22 clustering protocols and different variants of LEACH
2012 [42]	Sha *et al.*	surveyed multi-path routing protocols for WSNs, which are classified into three categories, infrastructure-based, non-infrastructure-based, and coding based
2012 [43]	Radi *et al.*	proposed an idea about the multi-path routing approach and its crucial difficulties with a taxonomy. Summarised multi-path routing methods from the system application perspective.
2012 [44]	Liu	presented a blueprint on favourable circumstances and targets of clustering for WSNs with a novel taxonomy dependent on clustering characteristics
2012 [45]	Goyal and Tripathy	reviewed on various levelled and area-based conventions protocols their depiction with favourable circumstances and hindrances
2012 [46]	Pantazis *et al.*	discussed energy-efficient routing protocols are classified them into four main categories and further explained with the various environments
2012 [47]	Haneef and Zhongliang	reviewed and examined the testing factors in WSN clustering and examined different routing protocols in WSNs. Established correlation among traditional clustering routing algorithms for WSNs
2012 [5]	Huang *et al.*	presented the evolution of WSN medium access control (MAC) protocols. Proposed a classification on WSN MAC evolution.
2012 [48]	Mundada	presented a classification of routing protocols based on application-specific in WSN. Discussed the advantage and disadvantages of routing techniques.

Table 3 Chronological presentation of existing survey works from 2003 to 2019

Year	Authors	Uniqueness of contribution
2013 [3]	Mahapatro and Khilar	surveyed fault diagnosis and related existing work specifically for WSN. Proposed a potential based taxonomy.
2013 [49]	Masdari and Tanabi	proposed a review on multi-path routing protocols of WSN with its advantages. Presented a new classification based on specific attributes.
2014 [50]	Alrajei and Fu	surveyed fault tolerance in WSN in general terms
2014 [51]	Rault *et al.*	presented a top-down approach study of the trade-off between application requirements and lifetime. Presented a new classification of energy-conservation schemes found in recent literature.
2015 [52]	Nigam and Dabas	discussed the 13 clustering protocols along with their advantages and disadvantages
2015 [53]	Kumrawat and Dhawan	done a comparative analysis with ten protocols on the basis of connectivity, mobility, identification, and combined weight
2016 [8]	Mitra *et al.*	studied and analysed various fault tolerance techniques in homogeneous WSN
2016 [54]	Sucasas *et al.*	surveys the state-of-the-art in clustering techniques and explained a detailed description of the basics of clustering with the latest ideas. Illustrated open issues, technical challenges, and directions for future research.
2016 [55]	Joshi and Kim	outlined the objectives, requirements, and advantages of node clustering in cognitive radio (CR)-WSNs. Surveyed the existing clustering algorithms and compared their objectives and features.
2017 [56]	Arjunan and Pothula	comprehensively surveyed various unequal clustering approaches with their objectives and characteristics. Furthermore, classified the unequal clustering approaches based on various clustering and CH properties and processes.
2017 [57]	Gherbi *et al.*	summarised recent research results on data routing in SeN and classified the approaches into four main categories
2017 [58]	Jan *et al.*	highlighted and discussed the design challenges for cluster-based schemes, the important cluster formation parameters, and classified hierarchical clustering protocols
2017 [59]	Rostami *et al.*	investigated and compared various homogeneous and heterogeneous methods of clustering
2017 [60]	Kobo *et al.*	discussed the new approaches for efficiency and sustainability of WSNs. Presented a comprehensive review of the software defined wireless sensor network (SDWSN) literature with open issues.
2017 [61]	Ogundile and Alfa	surveyed on the different state-of-the-art energy-efficient and energy-balanced routing protocols. Presented a taxonomy to classify the surveyed energy-efficient and energy-balanced routing protocols based on their proposed mode of communication towards the BS.
2018 [62]	Al-Shalabi *et al.*	surveyed on cluster formation and CH selection methods. Presented a new taxonomy to discuss LEACH variants on the basis of different classes.
2018 [63]	Riaz	surveyed on a total of 35 clustering protocols and compared these protocols based on these metrics such as 'heterogeneity', clustering method, size of the cluster etc.
2019 [64]	Coluccia and Fascista	reviewed recent developments in wireless localisation. Focused on cooperation attribute among mobility, array processing in the context of 'crowd-sensing'.
2019 [65]	Awan *et al.*	conducted a survey on underwater WSNs where the focus was paid on routing protocols, localisation, effect of packet size, channel strength, and MAC. The objective was to provide new opportunities by analysing the existing models.

transmission process is a combination of two sub-communication processes. The communication initiates between SN and CH, which comes under intra-cluster communication. The second communication occurs between CH and BS, which comes under inter-cluster communication.

The deployment of the SN in the cluster can be of two types such as centralised or distributed. The CH selection process in WSN may be in three ways, i.e. probabilistic, non-probabilistic, and iterative manner. In this subsection, we briefly elaborate on the evolution of clustering algorithms. Our study on 30 selected algorithms provided us an evolutionary approach of clustering towards fault tolerance approach. The approaches are hierarchical, heuristic, meta-heuristic, hyper-heuristic, and hybrid. Fig. 5 illustrates the time-series approaches of clustering algorithms in WSN. Based on several attributes of SN, the SeN is again classified into various sub-categories such as

i. Homogeneous and heterogeneous networks
ii. Centralised or distributed clustering algorithms
iii. Static and dynamic clustering
iv. Non-probabilistic and probabilistic approaches
v. Non-uniform and uniform clustering approach

Hierarchical: The hierarchical method is the beginning of the clustering scheme, which may be called the first generation of clustering. Furthermore, this approach is classified into two main categories such as cluster-based and grid-based. In the cluster-based approach, the cluster is managed by a resourceful dominating node called CH. In the case of the grid-based approach, the total SeN is going through a virtual-partition process, which is managed by the BS.

Heuristic: As per our study, we have categorised heuristic algorithms under the second generation of the clustering approach. It primarily intends to find a solution from all possible ones and at the same time, it cannot guarantee the best performance so there is always an open end to enhance the heuristic algorithms. The performances of heuristic algorithms are very close to the expected results. In this approach, a very specific problem area is usually targeted by ignoring other issues. The routing algorithms through the clustering process normally fall under the heuristic category. As routing is a dynamic state of problem it may have different solutions at different points of time. The algorithms under this category again classified into two types: weighted and dynamic-weighted approach. The greedy nature of the heuristic approach, most of the time trapped the algorithm in local optimum rather in general.

Meta-heuristic: The meta-heuristic algorithms adopt problem-independent methods, which may be categorised as the third generation of the clustering approach. As it is a non-greedy approach, hence it will not take any advantage of the specificity of the problem. Here, the non-greedy approach means it will not look for the best solution for a particular moment rather it looks for a solution which is true in all circumstances. It is popularly used for clustering algorithms in WSN. It was observed that in many clustering approaches the behaviour of the simulation process is always fluctuating at a different point in time which concludes that

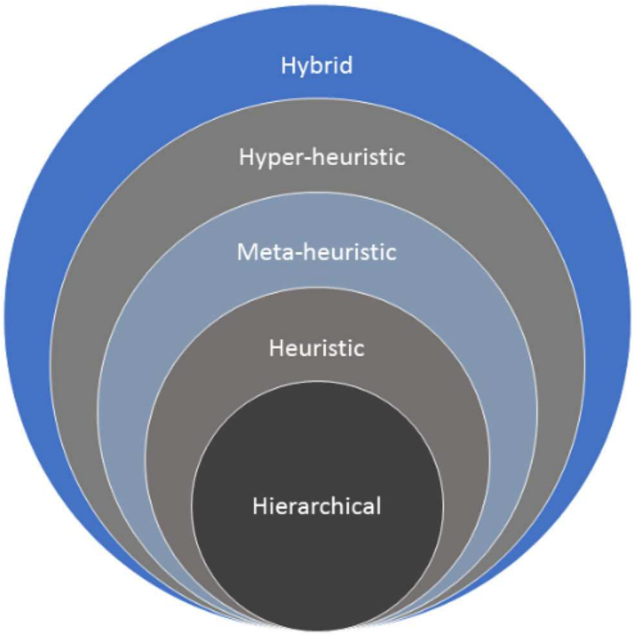

Fig. 5 *Evolution of clustering approaches*

the meta-heuristic approach accepts the temporary deterioration of the solution. Similar to heuristic, it does not guarantee the exact solution to the problem. Sometime meta-heuristic approaches are based on natural or man-made metaphors to solve nondeterministic polynomial (NP)-hard problems.

Hyper-heuristic: The fourth generation, i.e. hyper-heuristic is one-step-ahead than meta-heuristics. Here, there is no explicit search space rather it uses space of heuristic and meta-heuristic. So it can be viewed as 'heuristics to search for heuristics'. In other words, in the hyper-heuristic process, the objective is not to solve the problem rather finding sequential heuristic steps towards solving the problem. So, it can be referred to as designing technique which combines all possible heuristic solutions in such a manner, which will cumulatively provide a solution [66]. The very first-time use of the hyper-heuristic concept can be found in [67]. The progression of this concept gradually found in scheduling algorithms [68, 69].

Hybrid: It is a clustering category without any specific form, which may be recognised as the fifth generation of the clustering approach. Depending upon the problem nature, the solution space may belong to several domains. For example, routing with energy optimisation where we have two problem spaces that are efficient routing and clustering with energy efficiency. In such a case, a hybrid approach is required where we can adopt different solution spaces for a different problem. The possible combinations are as follows:

i. hierarchical + heuristic,
ii. heuristic + meta-heuristic,
iii. hierarchical + meta-heuristic.

3.1 Hierarchical approaches

3.1.1 low-energy adaptive clustering hierarchy (LEACH): In [70], the authors proposed a 'LEACH' algorithm. The core functionality of 'LEACH' defines that the role of CH is not limited to a specific group of nodes rather it is open to all SNs of SeN. The criterion to be CH is the current R_e level of an SN must be equal or higher than the prefixed threshold value of T_h. LEACH adopts a probabilistic approach to select CH. The goal of rotational basis CH selection is not to overburden any SN. The limitation of LEACH is the repetitive involvement of all SNs in the CH selection process during each electoral round. This iteration of cluster formation itself is a substantial energy consumption process that violates the objective of minimum energy consumption.

3.1.2 Stable election protocol (SEP): In [71], a clustering algorithm named 'SEP' was introduced. SEP acts with the heterogeneity concept, i.e. the combination of 'normal nodes' (NNs) and 'advanced nodes' (ANs) (nodes, which are resourceful when deployed) in SeN. Only ANs can act as a CH and to perform data aggregation while the NNs can either be a transmission node for its data but cannot perform any of the functions that are specific for CH only. The major constraint of SEP is it is applicable when the SNs are statically deployed and uniformly distributed.

3.1.3 Hybrid energy-efficient distributed (HEED): In [72], a new clustering protocol called 'HEED' was proposed. The objectives of HEED are to support scalable data aggregation and enhance the lifetime of the network. The HEED works with two major parameters such as (i) hybrid residual energy and (ii) degree of a node (to neighbours). It works with three major objectives such as (i) to balance the energy consumption among different parts of the SeN, (ii) efficient utilisation of remaining R_e, and (iii) counting of node density as primary parameters for the selection of CH. These three objectives lead the HEED towards efficient distribution and energy consumption for prolonging the lifetime of the SeN, secondly the selection of CH after a fixed or pre-fixed number of iterations, and third proper localisation of CH by considering easy access of SNs.

3.1.4 Distributed weight-based energy-efficient hierarchical clustering (DWEHC): In [73], an efficient routing protocol was proposed, which focuses on the formation of a balanced cluster. The proposed algorithm is weight centred and improving intra-cluster level communication. Each SN is able to judge its degree by counting the directly connected nodes and to calculate the remaining R_e. The node with the highest R_e or weight is elected as CH and the rest as CM. These CMs are known as first level CMs. The execution of DWEHC begins with the calculation of weight and distance to its neighbours. This process may terminate with O(1) iteration.

3.1.5 Distributed energy balance clustering (DEBC): Its function is identical to 'LEACH' where the CH is selected as per the remaining R_e of SNs. The remaining SNs excluding CH act as CMs for the next electoral round. This protocol was compared against 'LEACH' and 'SEP'. This work was extended with two-energy-level heterogeneity. The selection of CHs is a probability factor that depends upon the remaining R_e and average energy (AV_e) of WSN. The SNs with high R_e and initial energy have more probability to become a CH [74].

3.1.6 Unequal cluster-based routing (UCR): In [75], the authors have focused on the hot spot problem of multi-hop-count communication in WSN. The primary problem with multi-hop-count routing protocol is the CHs, which are closer to the BS die faster than other CHs because of overburden and heavy traffic that leads to a network partition problem. The proposed UCR protocol clubs the node into unequal sizes. The designing method says that the CHs closer to the BS have a smaller cluster than the farthest CHs. The reason behind this is the smaller size cluster leads to the preservation of energy for inter-cluster communication. This algorithm maintains the balance between the cost of the relay path and R_e of SNs.

3.1.7 Stochastic distributed energy-efficient clustering (SDEEC): The authors of [76] divided the network into dynamic clusters. The CMs send their data to elected CH and CHs forward aggregated data to the BS. This algorithm adopted a stochastic method to prolong the SeN lifetime. SDEEC is basically the extension of the distributed energy-efficient clustering (DEEC) protocol. According to this protocol, the initial energy and R_e are considered to elect CH. To achieve this, all CMs must need to have the overall knowledge of SeN.

3.1.8 Stochastic and equitable DEEC (SEDEEC): The authors of [77] adopted a stochastic and equitable uniform energy distribution technique. This protocol uniformly distributes energy in the whole SeN. It uses dynamic probability for CH selection. The major focus of this protocol is to manage energy efficiently when the CH is situated far away from the BS.

3.1.9 Stochastic and balanced developed DEEC (SBDEEC): The authors of [78] proposed the SBDEEC protocol for the heterogeneous WSN. The protocol divides the whole network into dynamic clusters. The CMs communicating with CH and CH with BS. It adopted a dynamic and balanced CH selection process. This algorithm aims to enhance the network lifetime and the result was compared against SEP and DEEC. This is the extension of DEEC where the initial energy and R_e are considered for CH selection.

3.1.10 Mobile nodes-based clustering protocol (MNCP): In [79], the proposed MNCP solves the problem of energy hole, which is created by low R_e of the SNs. Whenever the CH election problem arises, the mobile SNs are instructed to move such a zone and to mitigate the low R_e problem. This mobile node replaces the low R_e-based CH and plays an active role in CH for uninterrupted communication.

3.1.11 Partitioned based energy efficient LEACH (PE-LEACH): In [4], a very recent LEACH variant was proposed where the authors compared the proposed algorithm performance against both hard and soft computing-based algorithms. The three major objectives that the PE-LEACH addressed are (i) avoidance of unnecessary involvement of all SNs in CH election process, (ii) avoid multi-hop communication process, and (iii) enabling direct communication between CH and BS by making BS as mobile in nature.

3.2 Heuristic approach

3.2.1 Deterministic energy efficient clustering (DEEC): In [80], a multilevel clustering protocol was proposed, which was explicitly designed for a heterogeneous environment. In this protocol, the CH is elected based on R_e in comparison with the average network energy as the baseline threshold. This protocol is based on two levels of energies and all the SNs have an idea about the energy of all the rest. The proposed algorithms are distributive, dynamic, and self-sorted. The DEEC reduces the uncertainty of the CH selection problem.

3.2.2 Developed DEEC (DDEEC): The authors of [81] have proposed a clustering protocol for heterogeneous WSN, which is an extension of DEEC. The initial energy and R_e are considered for the election of CH. The SNs know the total SeN. The algorithms work on a fixed and no-varying time environment. There are two types of nodes such as NN and AN, which defines the CH probability.

3.2.3 Cluster-based service discovery (C4SD): In [82], the authors have proposed an algorithm for heterogeneous WSN named 'C4SD' protocol. Here, the focus was given on minimising the service discovery cost and maintenance of the service registry. To achieve this, the following factors are considered such as decisions based on single-hop neighbour information, the creation of sparsely distributed CHs, and avoid chain reactions.

3.2.4 Energy efficient heterogeneous cluster (EEHC): In [83], the algorithm electing a CH in the distributed fashion in a hierarchical WSN. The probability of an election for CH depends upon the initial energy of a node. The CMs are communicating with CH and CH communicates with BS. Here three types of the node have been considered where each node has a different threshold value. This clustering technique forms equal-sized clusters due to different cluster counts.

3.2.5 Distributed CH election (DCHE): In [84], a distributed CH election approach was proposed. Every SN of the SeN is assigned with some weight. The CH election is based on the weighted probability of SNs. This algorithm uses a 'time division multiple accesses (TDMA)' schedule, which allows the SNs to act whenever there is the availability of data to transmit or else the SNs may go to sleep state. The CMs send their collected data to CH and CH forwards that data to the BS.

3.2.6 Energy efficient clustering scheme (EECS): In [85], the CH selection is based on a weighted probability function. The probability function was calculated by using three parameters such as initial energy against current R_e, time consumption for total data transmission, i.e. from CM to BS through CH, and the count of nodes that have already played the role of CH. This algorithm focused on reducing the R_e level of CM by using the above factors.

3.2.7 Weighted election protocol (WEP): In [86], the overall objective is to increase the stability of the WSN. According to this routing protocol, each SN is assigned with a weight, which is equal to the ratio between the initial energy of each SN and NN. In the process of enhancing stability and energy efficiency, the WEP adopts the CH selection process such as LEACH. The new chaining CH selection method selects CH randomly. The rest CH becomes CM and send its data to the CH and from that point to the BS.

3.2.8 Energy balanced cluster formation (EBCF): In [87], the authors introduced a novel approach of clustering where the whole focus on cluster level equilibrium energy distribution, which influences both cluster and node-level fault handling. Initially, the authors counted the numbers of SNs and their R_e in SeN. Next, by applying the partition distribution function, the authors divided the total network into equal-strength clusters, which ensure the equilibrium energy dissipation within all clusters.

3.2.9 Power-efficient zoning clustering algorithm (PEZCA): In [88], a cluster-based energy effective routing convention was proposed. The creators joined two understood clustering conventions: 'LEACH' and power efficient gathering in sensor information systems (PEGASIS) to get the ideal execution from their proposed convention. In this convention, the BS is situated in the focal point of the fan-modelled sensor organise and the groups that are far from the BS have higher node density than the clusters close to the BS.

3.2.10 Heuristic algorithm for clustering hierarchy (HACH): The proposed HACH protocol [89] is a heuristic algorithm that has been designed to select non-active nodes and CH during each round. For non-active node selection, it adopted a stochastic sleep scheduling algorithm, which confirms regarding the SNs needed to allow for sleep state without disturbing the network coverage. Also, a novel heuristic crossover operator has been used for the efficient distribution of CH and coordinating the energy consumption of the WSN.

3.3 Meta-heuristic approach

3.3.1 Ant colony optimisation clustering (ACO-C): The main objective behind the simplified-ACO is to replicate the behaviours of ants in search of foods. The algorithm proposed in [90] is very similar to the original ACO algorithm. Here, the authors proposed a combinatorial way such as fuzzy c-means (FCM-ACO) and hard c-means (HCM-ACO) with specific instances. This is a meta-heuristic model that does not consider any specific clustering model.

3.3.2 Particle swarm optimisation-clustering (PSO-C): In [91], the authors have proposed an energy-aware clustering for WSN by using the PSO technique. The objective of PSO is to reduce the intra-cluster distance and to optimise the energy consumption of the SeN.

Table 4 Comparative analysis (advantages and disadvantages)

Factors	Possible values	Hierarchical	Heuristic	Meta-heuristic	Hyper-heuristic	Hybrid
deployment pattern	uniform (U)/non-uniform (NU)	U/NU	U/NU	U/NU	U/NU	U/NU
heterogeneity	yes and its values (numeric)	yes/2	yes/2	yes/2	yes/2	yes/2
clustering method	centralised (C)/distributed (D)/hybrid (H)	C/D	C/D	C/D/H	C/D	H
CH/CM mobility	static (S)/dynamic (D)	S/D	S/D	S/D	S/D	S/D
cluster	fixed (F)/variable(V)	F/V	F/V	F/V	F/V	F/V
intra-cluster communication	single-hop (SH)/ multi-hop (MH	SH/MH	SH/MH	SH/MH	SH/MH	SH/MH
CH and BS communication	direct (D)/indirect (ID)	D/ID	D/ID	D/ID	D/ID	D/ID
probability	pure (P)/weighted (W)	P	W	W	W	P/W
neighbourhood distance	known (K)/unknown (UK)	UK	U/UK	UK	U/UK	U/UK
neighbourhood location	known (K)/unknown (UK)	UK	U/UK	UK	U/UK	U/UK
type of fault	hardware (H)/software (S)/communication (C)	H/S/C	H/S/C	H/S/C	H/S/C	H/S/C

3.3.3 Social insect colonies-clustering (SIC-C): In [92], the authors proposed a decentralised clustering algorithm for WSN based on the biological social insects. In the proposed approach, each insect is analogous to an SN of SeN. In cluster architecture, the CH is queen insect and the relay nodes are the workers. The pheromone compound is represented by two aspects namely retinue compounds such as global control packets (GCPs) and queen mandibular pheromone (QMP) is represented by local control packets (LCPs) [92]. The CH will use the GCP and LCP data to control cluster members and their activities [92].

3.3.4 Cluster formation by using cuckoo search: In [93, 94], the authors proposed a meta-heuristic approach called cuckoo search technique for forming the energy-efficient clusters. According to this algorithm, the SNs are segregated into two types such as low R_e node and high R_e node. The low R_e nodes are responsible to collect the data by sensing the environment whereas, the high R_e nodes are assigned with data transmission function.

3.3.5 Harmony search algorithm (HSA): Optimising energy consumption is the main goal of this study [95]. The proposed HSA is meant for reducing intra-cluster distance and enhancing the network lifetime. The HSA is analogous with the music played by a musician who tries to maintain harmony between various instruments. Here, the HSA tries to maintain the same harmony between all SNs of SeN.

3.4 'Hyper-heuristic' approach

3.4.1 Hyper-heuristic clustering algorithm (HHCA) and effective hyper-heuristic algorithm (EHHA): In [96], the proposed algorithm was designed to enhance the network's lifetime. The HHCA is a high-performance-based meta-heuristic algorithm that is looking after the residual energy of SNs and their balancing factor. The validation of performance was done by comparing the LEACH protocol. The primary idea behind 'HHCA' is to solve the 'CH election problem' [97]. In [97], the EHHA has been proposed, which uses an additional operator called 'recording pool' for storing the best solutions (most suitable CH).

3.5 Hybrid clustering

3.5.1 Hybrid clustering algorithm (HCA): In [98], the authors proposed a 'hierarchical agglomerative clustering' and '*k*-means' algorithm to generate an optimum number of clusters and CHs.

3.5.2 Energy aware neighbour oriented clustering (EANOC): In [99, 100], the proposed EANOC aims to enhance the network lifetime. It is an improvised version of the 'hybrid weight-based clustering algorithm' [101] with focus on neighbour node discovery. The factors that are considered for efficient energy utilisation are a range of transmissions, the strength of receiver signal, and propagation model.

3.5.3 Hybrid ACO and PSO (ACOPSO): In [102], the authors proposed a hybrid algorithm, which is a combination of fuzzy c-means and ACO. The fuzzy c-means have been used to create a finite number of clusters, and ACO has been used for generating the shortest local path among the clusters. During the use of the first algorithm, the CH gets selected on the basis of remaining residual energy and the CH can communicate directly with the BS. By using the second algorithm, the global chain gets set up between all CHs for multi-hop communication.

3.6 Analysis

The thorough study on various clustering approaches concludes about the several parameters, which are normally considered for cluster classification in WSN. The factors are the pattern of deployment, nature of SeN, types of clustering methods, mobility of SNs, the distance between SNs and CHs, degree of a node, and kind of fault occurrence. Table 4 presents the comparative analysis between all the generations of clustering approaches on the basis of said factors. The comparison has been done by considering several factors such as deployment pattern, heterogeneity, clustering method, CH/CM mobility, cluster format, intra-cluster communication, CH and BS communication, probability, neighbourhood distance, neighbourhood location, and types of faults.

Through our study, we have understood that in all five types of clustering approaches, the deployment pattern either can be uniform or non-uniform, which is an application-specific decision. The second factor is heterogeneity, which is again a common factor for all clustering approaches. The term heterogeneity can be defined by several factors such as energy level, types of sensors, computational capacity etc. Similarly, the rest of the factors are more or less dependent upon the application and according to the applicable nature, and the appropriate clustering approach needs to be selected to get optimal performance.

3.6.1 Advantages and disadvantages of clustering approaches: Furthermore, we have analysed all the clustering approaches based on their advantages and disadvantages. By considering all the protocols that belong to each category, here we have analysed the advantages and disadvantages of each clustering approaches whereas these advantages and disadvantages again vary from clustering to clustering techniques.

Advantages of hierarchical clustering approach:

- Equal sharing of load achieved load balancing
- Avoid excessive energy consumption
- Avoid collision by the help of TDMA scheduling
- Energy-efficient routing
- Suitable for small and static network
- Improves network lifetime
- Suitable for a homogeneous network
- Optimal CH selection
- Resolves energy hole problem
- Works well with predefined node position

- Ensures continuous data flow
- Minimises network overhead
- Maintains approximately equal cluster size

Disadvantages of hierarchical clustering approach:

- Problem with inter-cluster communication because of single-hop communication
- CH selection through a probabilistic approach does not consider the energy level
- Extra overhead during dynamic clustering
- Re-selection of CH is resource consuming
- Not suitable for large-scale networks
- Non-optimised CH selection
- Iterative cluster formation leads to energy consumption
- Excessive message transfer
- CH selection process consumes substantial energy
- Random deployment of SN leads to difficulties in management
- Redundant message problem
- Effects of network lifetime due to iterative processes
- Only suitable for small-scale grids
- Long-distance placed SN may be elected as CH, which leads to rapid energy depletion
- Periodic calculation of residual energy level
- Communication may break because of sub-optimal CH selection
- Not suitable for mobile SNs
- CH selection mostly based on the distance factor
- Node isolation and partition of the network may be possible

All types of heuristic approaches behave very similar to each other. Hence, the advantages and disadvantages of all these approaches can be summarised in a single place.

Advantages of heuristic/meta-heuristic/hyper-heuristic clustering approach:

- If not exact it gives approximate results
- Works well both in uniform and non-uniform load distribution
- Avoid excessive energy consumption
- Avoid collision by the help of TDMA scheduling
- Optimal routing because of multi-hop communication
- Suitable for large and mobile networks
- Extends network lifetime
- Suitable for homogeneous and heterogeneous network
- Optimal CH selection and avoid iterative work
- Resolves energy hole problem
- Works well with mobile node position
- Minimises network overhead
- Maintains approximately equal cluster size
- CH selection through a non-probabilistic approach

Disadvantages of heuristic/meta-heuristic/hyper-heuristic clustering approach:

- Extra overhead during dynamic clustering
- Re-selection of CH is resource consuming
- Non-optimised CH selection
- Iterative cluster formation leads to energy consumption
- Excessive message transfer
- CH selection process consumes substantial energy
- Random deployment of SN leads to difficulties in management
- Redundant message problem
- Effects of network lifetime due to iterative processes
- Periodic calculation of residual energy level
- Communication may break because of sub-optimal CH selection

Advantages of hybrid clustering approach: The hybrid clustering approach is the combination of more than one clustering technique hence it covers all the advantages as its strength. The disadvantage in the hybrid approach is the handling of fault occurrences as it is a combination of approaches.

- It gives both exact and approximate results
- Works well both in uniform and non-uniform load distributions
- Avoid excessive energy consumption
- Avoid collision by the help of TDMA scheduling
- Optimal routing in both single-hop/multi-hop communication
- Suitable for large and small and mobile network
- Extends network lifetime with fault tolerance
- Suitable for homogeneous and heterogeneous network
- Optimal CH selection and avoid iterative work
- Resolves energy hole problem
- Works well with mobile node position
- Minimises network overhead
- Maintains approximately equal cluster size
- CH selection through a non-probabilistic approach
- Suitable for both small- and large-scale grids

Disadvantages of hybrid clustering approach:

- Fault isolation is difficult
- Dependency among clusters creates method selection confusion
- Re-selection of CH is resource consuming
- Non-optimised CH selection if the CH selection is hierarchical
- Iterative cluster formation leads to energy consumption
- Excessive message transfer if the combination is hierarchical and heuristic
- CH selection process consumes substantial energy
- Random deployment of SN leads to difficulties in management
- Redundant message problem if the SNs are deployed closely
- Effects of network lifetime due to iterative processes if the combination is hierarchical and heuristic
- Periodic calculation of residual energy level if the CH selection is hierarchical
- Communication may break because of sub-optimal CH selection

The selection of clustering approaches is purely based on the applications and constraints of the network to be set-up. The advantages and disadvantages of these clustering approaches help to understand the strength and weakness of individual clustering approach. The harsh and hostile deployment pattern of WSNs must be incorporated with clustering technology for the lifetime and fault tolerance.

4 Conclusion

The several benefits of wireless communication over wired communication are able to generate many expectations in modern research. The versatility of sensor-based communication shows a great promising paradigm for remote communication. Several clustering approaches and algorithms have been proposed in recent years. In this study, we have presented a generation wise review on clustering approaches. A generation wise model indicates the motion of clustering methodology, which is necessary to understand for predicting future work. In this study, we have presented a review on clustering algorithms that are categorized based on the generation of clustering. Based on our study, we also presented a comparative analysis among the proposed generation of clustering techniques. Additionally, we have presented a summary by analysing their advantages and disadvantages among all clustering approaches. Furthermore, we have presented a calendar wise summary table on existing survey works in the field of WSN, which covers well-known survey works from 2002 to 2019. These are the key features of this study, which exhibit uniqueness in comparison with the existing work. We hope this work serves both as a reference document to understand various existing survey literature and as a tutorial to understand clustering algorithms.

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