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A Quotient Space Based Clustering Protocol for WSNs

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Abstract: Recently considerable growth in the development of cluster based routing protocols is not only used to optimize the Wireless Sensor Networks (WSNs) resources but also increase the performance and reliability of the WSNs applications. However, dynamic behavior of sensor node such as energy consumption, geographical distribution and other complex factors makes the design of cluster based routing algorithm a challenging task. In this study, recent research for developing clustering protocols is highlighted and limitations are identified. Based on these limitations, a new granular method for dynamic grid routing protocol based on Quotient Space theory is proposed. The algorithm achieved the efficient clustering by accomplishing the effective comparison and transformation among quotient sets with different granularities. It can comprehensively consider node energy consumption; residual energy balance and geographical distribution balance. Furthermore, the optimal number and shape of cluster is dynamically calculated instead of relying on prior knowledge. The experimental result shows efficient energy and network lifetime as compared to other similar methods in WSNs.

Key words: Wireless sensor network, clustering algorithm, granular computing, hierarchical, quotient space

INTRODUCTION

WSNs collaboratively perceive, collect and process the objects' information in the network coverage area which has a broad application prospect in the military, industrial, medical, traffic, family and other fields. Compared with traditional wireless network, the resource of WSN nodes is very limited, mainly battery power, processing ability, storage capacity and communication bandwidth (Akyildiz *et al*., 2002; Gupta and Younis, 2003).

The design of routing algorithm for sensors is a fundamental issue in WSNs and it can affect the lifetime of network. Recently, more and more protocols prefer the clustering strategy because of less communication and good scalability. Clustering algorithm groups the sensor nodes into clusters which can improve the network lifetime efficiently in large-scale WSNs and also enhance network stability and robustness.

If every sensor starts to communicate and engages in data transmission in the network, data congestion and collisions will be experienced. This will drain energy quickly from the sensor network. Clustering is a method used to overcome these issues. Two main steps used in clustering process are Cluster Head (CH) selection and cluster formation. In clustered networks, some sensors are selected as Cluster Heads (CHs) for each cluster created. A CH may be just one of the sensors or a node that is rich in its resources. The cluster member may be fixed or variable. Most of algorithms select CHs first and then decide clustering and routing and some of algorithms pre-assign the cluster, then select the CH and make routing strategies. Sensor nodes in each cluster transmit their data to the respective CH and the CH aggregates data and forwards it to a central base station. Clustering facilitates efficient utilization of limited energy of sensor nodes and hence, extends network lifetime (Abbasi and Younis, 2007; Wei *et al*., 2008; Forster *et al*., 2010; Kumar *et al*., 2011). Generally, an efficient clustering algorithm needs to meet the following requirements: (1) Through a balanced load, avoid the energy of a single node premature depletion to prolong network lifetime, (2) Fast convergence, (3) Reduce the quantity of control information and (4) Efficient distribution of cluster heads.

In this study, comparison and evaluation of main clustering algorithm is performed and limitation of existing clustering algorithms are identified. Based on the limitation, a new approach named "dynamic grid routing protocol based on Granular computing Quotient Space theory is proposed. This new approach can dynamically consider node energy consumption; residual energy balance and geographical distribution balance. Furthermore, the optimal number and shape of cluster is calculated dynamically instead of relying on prior knowledge.

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WSNs CLUSTERING PROTOCOLS

Low-Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman *et al*., 2000) is initial algorithm proposed for WSNs clustering. LEACH is able to distribute energy dissipation evenly throughout the sensors, doubling the system lifetime for the networks. It randomly selects a number of CH by setting the probability and the whole network energy load is evenly distributed to each sensor node which can reduce network energy consumption and prolong network lifetime. The main problem with LEACH lies in the random selection of cluster heads. There exists a probability that the cluster heads formed are unbalanced and may remain in one part of the network making some part of the network unreachable. Also, one-hop inter and intra-cluster used in LEACH is not applicable for large region networks.

The SEP (Smaragdakis *et al*., 2004) uses similar clustering method like LEACH but in SEP's protocol, the nodes in the network are divided into two parts, the nodes of higher energy called high energy nodes, low energy called normal nodes, high energy nodes and normal nodes have different cluster head selection threshold and different probability to become CH, high energy nodes has greater chance to become CH over low energy nodes. As compared to LEACH in heterogeneous network, SEP balanced the survival time of both node types effectively and also efficient energy consumption for WSNs.

Distributed Efficient Clustering (DEEC) (Qing *et al*., 2006) is dedicatedly designed for heterogeneous scenarios of energy, where nodes are initialized at various energy levels. In DEEC, the cluster-heads are selected by a probability based on the ratio between residual energy of each node and the average energy of the network. The epochs of being CHs for nodes are different according to their initial and residual energy. The nodes with high initial and residual energy have more chances to be the CH than the nodes with low energy. As compared to LEACH, DEEC can make better use of the energy for WSNs and extend the network lifetime.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) (Lindsey and Raghavendra, 2002) is a near optimal chain-based protocol that is an improvement over LEACH. It makes a communication chain using a Traveling Sales Person heuristic, each node communicates only with a close neighbor and takes turns transmitting to the base station, thus reducing the amount of energy spent per round. Simulation results show that PEGASIS performs better than LEACH by about 100-300% when 1, 20, 50 and 100% of nodes die for different network sizes and topologies.

Hybrid Energy-Efficient Distributed clustering (HEED) (Younis and Fahmy, 2004), periodically selects cluster heads according to a hybrid of the node residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. HEED terminates in O(l) iterations, incurs low message overhead, efficient energy consumption and achieves fairly uniform cluster head distribution across the network.

In LEACH-CC (Li and Zhang, 2012) each cluster-head receive form and transmit to close neighbor cluster-head and take turns being the leader for transmission to the base station. This approach distributes the energy load evenly among the sensor nodes in the network and extends the network lifetime.

Grid-clustering routing protocol (GROUP) (Yu *et al*., 2006) is a grid-clustering routing protocol that provides scalable and efficient packet routing for large-scale WSNs. The sink proactively, dynamically and randomly builds a cluster grid structure. Only small part of all sensor nodes participates in selection of cluster heads. GROUP can distribute the energy load among the sensors in the network and provide in-network processing support to reduce the amount of information transmitted to the sink. The results of simulation show that GROUP is an energy-efficient and scalable routing protocol for large-scale WSNs.

Geographic Adaptive Fidelity (GAF) (Xu *et al*., 2001) is an energy aware location-based routing algorithm designed primarily for mobile ad hoc networks but is used in sensor networks as well. In GAF protocol, location information are used based on GPS to associate itself with a "virtual grid" so that the entire area is divided into several square grids and the node with the highest residual energy within each grid becomes the master of the grid. By identifying equivalent nodes with respect to forwarding packets, this protocol can optimize the performance of WSNs.

Grid-Based Stateless Routing (GBSR) is a new grid-based geographical routing protocol for the energy consumption of WSNs which are of high density and based on GPSR (Greedy Perimeter Stateless Routing) (Karp and Kung, 2000). On the premise of retaining network connectivity, the new protocol partition the monitoring area into grids using GAF algorithm and then turning off non-leader nodes to reduce energy consumption. Grid partition, sleeping mechanism and routing are designed and optimized. As compared to GPSR, simulation results show GBRS is an efficient routing protocol.

Adaptive Routing Algorithm (ARA) (Sacaleanu *et al*., 2011) suits especially for grid WSN. The algorithm takes into account the residual energy of the sensor nodes and configures the paths in order to maximize the network lifetime. It also presented data aggregations techniques based on temporal and spatial correlation characteristic for monitoring and data acquisition from sensor networks. Comparing ARA with existing WSN grid algorithms it highlights the advantages of using the routing algorithm together with the data aggregation technique.

HGAF (Inagaki and Ishihara, 2007) introduces to divide a grid into sub-grids. By selecting an active node from one sub-grid of each grid and synchronizing the relative position of the selected sub-grid, the position of active node is roughly synchronized. The expansion of GAF based on this idea is called Hierarchical GAF (HGAF). HGAF makes optimum use of energy for WSNs.

In Virtual Square Grid-based Coverage Algorithm (VSGCA) (Liu *et al*., 2013), the sensing area of each sensor node is divided into virtual square grids. The dividing method constructs the set of grids in a node. If all the grids are covered by neighbors, the target node is redundant node. It not only guarantees that the monitoring area is covered by sensors fully but also decreases the computational complexity and achieves best performance with fewer active nodes. Simulation results show that VSGCA can achieve better performance as compared to other algorithms.

Energy-Aware Grid-based Routing Scheme (EAGER) (Chi and Chang, 2013) is an approach that used in WSN dynamic topology with mobile observers it can save more energy. EAGER uses a rerouting method to identify and reconstruct new data dissemination paths between the source and multiple mobile sinks. The simulations show EAGER is better than other grid-based schemes in both routing performance and energy efficiency.

GAF-h (Liu *et al*., 2006) is proposed to use the honeycomb virtual mesh to replace the square grid in GAF. GAF-h is proved to be able to achieve zero loss with little extra cost compared to the original GAF scheme. It integrates nicely with the original GAF protocol with little computing overhead.

Honeycomb Architecture for Energy Minimum-cost in WSNs (HAEM) (Yuandong and Ping, 2009) is proposed to use honeycomb architecture topology. It optimized GAF algorithm topology and every node in each grid can communicate with nodes in adjacent grid. At the same time, HAEM can multicast data to save more energy. Simulation result shows HAEM is effective to prolong the lifetime of WSNs.

A comprehensive comparison of recent clustering protocols is shown in Table 1 and 2.

LIMITATIONS OF EXISTING CLUSTERING ALGORITHMS

It is observed from comparative analysis that the existing techniques proposed for WSNs clustering have the following limitations:

- Most of the algorithms do not take into account the heterogeneous sensor, such as LEACH (Heinzelman *et al*., 2000), PEGASIS (Lindsey and Raghavendra, 2002), HEED (Younis and Fahmy, 2004), LEACH-CC (Li and Zhang, 2012), GROUP (Yu *et al*., 2006), GAF(Xu *et al*., 2001), GBSR, ARA (Sacaleanu *et al*., 2011), HGAF (Inagaki and Ishihara, 2007), VSGCA (Liu *et al*., 2013), EAGER (Chi and Chang, 2013), GAF-h (Liu *et al*., 2006) and HAEM (Yuandong and Ping, 2009). The initial energy of sensor may be different and the algorithm should tackle with heterogeneous sensor and also reduce energy consumption. The existed algorithm like SEP (Smaragdakis *et al*., 2004), DEEC (Qing *et al*., 2006) divide the energy of sensors into different levels and select CH according to the residual energy. If the node has more energy it will have more chance to become CH. The proposed algorithm will use equivalence relation to balance the energy of each cluster and then select CH using weighted formula to consider the residual energy
- Most of the algorithms cause communication overhead, such as LEACH (Heinzelman *et al*., 2000), SEP (Smaragdakis *et al*., 2004), DEEC (Qing *et al*., 2006), PEGASIS (Lindsey and Raghavendra, 2002), HEED (Younis and Fahmy, 2004), LEACH-CC (Li and Zhang, 2012). They use global broadcast method to send message which consume more energy and decrease network lifetime. The proposed algorithm uses local broadcast to notice the related nodes and reduce messages
- In some algorithms such as LEACH (Heinzelman *et al*., 2000), SEP (Smaragdakis *et al*., 2004), DEEC (Qing *et al*., 2006), PEGASIS (Lindsey and Raghavendra, 2002), HEED (Younis and Fahmy, 2004) and LEACH-CC (Li and Zhang, 2012), it is difficult to consider the geographical distribution of cluster head, the energy balance of cluster nodes and other complex environmental factors at the same time

Usually, these algorithms select cluster head first and then form clusters and decide routing. The geographical distribution of cluster head may be

Table 1: Comparison and evaluation of clustering algorith

Clustering algorithms	Algorithm complexity	Application type	Optimum criteria	Broadcast method	Network type	Network size (Nodes)	Network area	Packet length	Node mobility	Location awareness	Energy efficiency
LEACH (Heinzelman *et al*., 2000)	Fast	General	Network lifetime	Global broadcast	Homogeneous	100	(100×100)	2000 bits	Stationary	Not required	Average
SEP (Smaragdakis *et al*., 2004)	Normal	General	Network lifetime	Global broadcast	Heterogeneous	100	(100×100)	4000 bits	Stationary	Not required	Good
DEEC (Qing *et al*., 2006)	Normal	General	Network lifetime	Global broadcast	Heterogeneous	100	(100×100)	4000 bits	Stationary	Not required	Good
PEGASIS (Lindsey and Raghavendra, 2002)	Complicated	General	Network lifetime	Global broadcast	Homogeneous	100	(100×100)	2000 bits	Stationary	Required	Good
HEED (Younis and Fahmy, 2004)	Fast	General	Network lifetime, Scalability	Global broadcast	Homogeneous	300	(100×100)	100 bytes	Stationary	Not required	Good
Leach-CC (Li and Zhang, 2012)	Normal	General	Network lifetime	Global broadcast	Homogeneous	100	(100×100)	4000 bits	Stationary	Not required	Good
GROUP (Yu *et al*., 2006)	Complicated	Real-time forest fire detection	Energy efficiency, scalability	Local broadcast	Homogeneous	300	(1200×1000)	-	Mobile	Required	Good
GAF (Xu *et al*., 2001)	Normal	Monitoring and Positioning	Energy efficiency, Scalability	Local broadcast	Homogeneous	-	-	-	Stationary	Required	Average
GBSR	Normal	General	Energy efficiency	Local broadcast	Homogeneous	100	(1000×100)	-	Stationary	Required	Good
ARA (Sacaleanu *et al*., 2011)	Complicated	Monitoring	Energy efficiency	Local broadcast	Homogeneous	81	(100×100)	2 byte	Stationary	Required	Good
HGAF (Inagaki and Ishihara, 2007)	Normal	General	Energy efficiency, scalability	Local broadcast	Homogeneous	-	-	-	Stationary	Required	Good
VSGCA (Liu *et al*., 2013)	Normal	General	Energy efficiency, Lower computational, complexity	Local broadcast	Homogeneous	-	-	-	Stationary	Required	Good
EAGER (Chi and Chang, 2013)	Complicated	Tracking and environmental surveillance	Network lifetime	Local broadcast	Homogeneous	-	-	-	Mobile	Required	Good
GAF-h (Liu *et al*., 2006)	Complicated	General	Energy efficiency	Local broadcast	Homogeneous	-	-	-	Stationary	Required	Good
HAEM (Yuandong and Ping, 2009)	Complicated	General	Energy efficiency	Local broadcast	Homogeneous	-	-	-	Stationary	Required	Good

Table 2: Classification of algorithms based on clustering attributes

Clustering algorithms	Cluster count	Cluster transmission	Cluster size uniformity	Cluster stability	Balanced clustering	Methodology	CH selection	Speed of CH selection
LEACH (Heinzelman *et al*., 2000)	Variable	Single-hop	Average	Moderate	Average	Distributed	Random	Fast
HEED (Smaragdakis *et al*., 2004)	Variable	Single-hop /Multi-hop	Average	High	Average	Distributed	Runtime	Fast
SEP (Qing *et al*., 2006)	Variable	Single-hop	Average	Moderate	Good	Distributed	Random	Fast
DEEC (Lindsey and Raghavendra, 2002)	Variable	Single-hop	Average	Moderate	Good	Distributed	Random	Average
PEGASIS (Younis and Fahmy, 2004)	Variable	Single-hop /Multi-hop	Average	High	Good	Distributed	Runtime	Average
LEACH-CC (Li and Zhang, 2012)	Variable	Single-hop /Multi-hop	Average	Moderate	Average	Distributed	Random	Fast
GROUP (Yu *et al*., 2006)	Constant	Single-hop	Good	High	Average	Distributed	Runtime	Average
GAF (Xu *et al*., 2001)	Constant	Single-hop	Good	High	Average	Distributed	Runtime	Fast
GBSR	Constant	Single-hop	Good	High	Average	Distributed	Runtime	Fast
ARA (Sacaleanu *et al*., 2011)	Constant	Multi-hop	Good	High	Average	Distributed	Runtime	Average
HGAF (Inagaki and Ishihara, 2007)	Constant	Single-hop	Good	High	Average	Distributed	Runtime	Fast
VSGCA (Liu *et al*., 2013)	Constant	Single-hop	Good	High	Average	Distributed	Runtime	Average
EAGER (Chi and Chang, 2013)	Constant	Single-hop /Multi-hop	Good	High	Average	Distributed	Runtime	Average
GAF-h (Liu *et al*., 2006)	Constant	Single-hop	Good	High	Average	Distributed	Runtime	Average
HAEM (Yuandong and Ping, 2009)	Constant	Single-hop	Good	High	Average	Distributed	Runtime	Fast

uneven and consume much energy when collecting and transmitting data. It leads to unbalanced energy in clusters and decrease WSN lifetime. The proposed algorithm use equivalence relation to balance the energy of each cluster and consider other complex environmental factors in equivalence relation. It also avoids uneven distribution of CH geography

- In grid based algorithms like GROUP (Yu *et al*., 2006), GAF (Xu *et al*., 2001), GBSR, ARA (Sacaleanu *et al*., 2011), HGAF (Inagaki and Ishihara, 2007), VSGCA (Liu *et al*., 2013), EAGER (Chi and Chang, 2013) or honeycomb clustering algorithms like GAF-h (Liu *et al*., 2006) and HAEM (Yuandong and Ping, 2009), it is not flexible enough to determine the number of clusters, size of the cluster and to adjust the cluster density. These algorithms are based on location division priority and then select CH it is easy to handle and achieve energy balance control to some extent. However, for the actual WSNs, the geographical distribution of sensor nodes are often uneven and energy consumption is also not balanced. The proposed algorithm uses the characteristics of sensors in cluster and makes a reasonable cluster division according to equivalence relation and the number of clusters. Size of the cluster can be adjusted dynamically when energy distribution of sensors changes
- In many studies, similar clustering number and energy consumption curve (Heinzelman *et al*., 2002; Kim *et al*., 2005; Chan *et al*., 2008; Li and Shen, 2008) is used as shown in Fig. 1. It can be observed from figure that clustering number and the ratio of the energy consumption is similar to the normal distribution graph and once the number of WSN clusters increase the overall energy consumption increase. Many studies are focusing on balance point of the optimal number of clusters but few studies discussed both the optimal number of cluster and the optimal clustering topology in WSNs

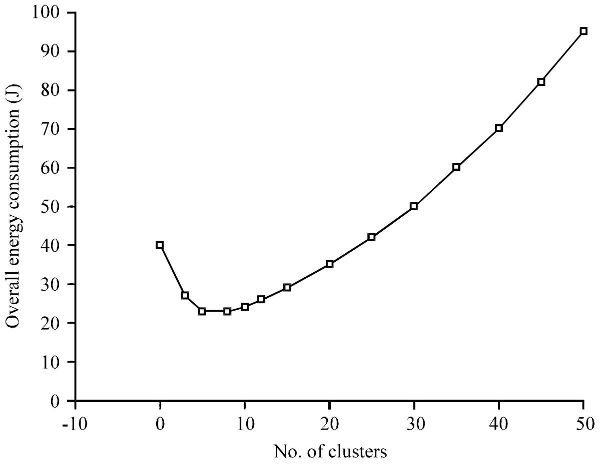

Fig. 1: Typical clustering number and energy consumption curve

PROPOSED CLUSTERING METHOD

It is observed from the analysis of existing clustering algorithm and their limitations that there is a need for flexible and dynamic clustering algorithm for WSNs. Currently, none of the clustering algorithms consider the geographical distribution and dynamic energy consumption in WSN. The previous algorithms are either based on the location division or cluster head selection strategy. Introducing granular computing based on quotient space (Zhang Ling, 2007) in clustering routing algorithm, is relatively a novel idea to address the geographical distribution and dynamic energy consumption in WSNs.

QUOTIENT SPACE THEORY

Granular analysis method is used to avoid the difficulties of high computational complexity, the original objects with high complexity can be decomposed in to some refined objects by some operator which is more convenient to analyze. The mutual conversion is a reflection of different granular space.

Quotient space theory model is a representative of granular theory and can be represented by a triple (X, f, T), where X is the domain, F is a set of attributes and T is a topology on X. The corresponding triple in refined space is denoted as ([X], [f], [T]) which is derived by equivalence relation R. Quotient space theory mainly studies the relationship of the quotient space and the quotient space synthesis, decomposition and reasoning. In this model, the mechanism of corresponding reasoning model follows two important properties, namely; “false preserving” and “truth preserving” property. The “false preserving” property means that if a proposition in the coarse granular space is false, then the proposition of refined granular quotient space must be false. The “truth preserving” property means that if a proposition in two refined granular quotient space is true, then (under certain conditions) in the synthesis of the corresponding quotient space, the proposition is also true.

Thus, WSN nodes cluster routing and data fusion can be considered as a special kind of multi-granularity information systems and the introduction of quotient space method helps to capture the spatial structure granularity changes. The use of Quotient Space theory in the clustering of WSN can reduce the energy consumption and the network performance is boosted.

WSN information system based on quotient space theory: Assume WSN is a complex Information System (IS): (X, f, T), which contains both spatial and energy consumption information, X is a nonempty finite object (sensor node) set, $X = \{X_1, X_2, ..., X_n\}$, where x_i is the object element (sensor node). The X can be defined as the number of nodes in original granularity. T is a topology on X, primarily reflecting elements of X on the relationship of the various nodes. For the domain of energy consumption of WSN nodes, using function f (X), that is, in the domain X has property function: f, $X \rightarrow Y$, where Y can be multidimensional, energy function f (X) is closely related to the location attributes, energy attributes, cluster head attributes in X and topological relationships T.

Assuming $R_1, R_2 \in R$ and $R_2 < R_1 \Leftrightarrow x, y \in X$, if there xR_1y, then xR_2y, where in xRy, R represents x and y are equivalent. This means that the domain X_1, which is corresponding to R_1, is more refined than the domain X_2 which is corresponding to R_2. Then R constitute a complete semilattice in relation "<". Therefore, the WSN clustering problem can be expressed as a granularity model. For a problem space (X, f, T) and the equivalence relation R on X, find the corresponding energy consumption is equivalent to locate optimal quotient space ([X], [f], [T]) which is a typical problem in granular computing.

Proposed clustering algorithm based on hierarchical quotient space: The basic idea of WSN clustering is to find the dynamic balance of energy consumption and extend the life of the WSNs. Through information system modeling and related theories, especially "false preserving" property of energy, dynamic grid routing algorithm based on the quotient space for WSN (QSRA) is proposed.

A WSN Information System (IS) for granular size analysis based on the X on the geographical location of the node property is to determine equivalence relation R, then IS can be divided into sub-cluster [IS] according to R equivalence classes. Each division is completed through IS divides into relatively independent sub-cluster [IS] according to R. So quotient space is up to the original space IS and equivalence relation R, different equivalence relation R can induce different quotient space. The hierarchical idea chooses different levels of granularity equivalence relation R, it can construct different levels of granularity clustering for WSNs from a coarse granularity to refined granularity. Through the research and discussion of IS and [IS] on various levels of granularity clustering topology T and energy f, we find it is helpful to extend the life cycle of WSN clustering.

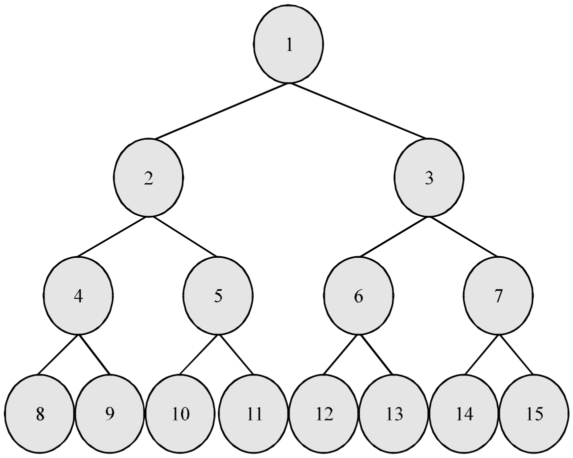

Fig. 2: Structure before clustering

If IS induced two sub-information systems IS_1 and IS_2, according to R, during the round before the communication obviously, we can get $IS = IS_1 + IS_2$. After the communication if the residual energy:

$$f(X) > \sum_{i=1}^{2} f(X_i)$$

where, f(x) is the energy consumption of the cluster . We asserts that IS can be divided in this granularity according to R, otherwise IS can't be divided in this granularity according to R.

The initial quotient space structure is shown in the Fig. 2; the nodes in the figure are possible effective clustering. In the optimal cluster formation process the algorithm evaluates energy consumption by hierarchical induction, removes the invalid or pruned cluster. After dividing, the node in this layer become invalid, the two nodes of next layer are the effective clusters of this branch. Evaluate energy consumption layer-by-layer until it cannot further divide and then prune the branch of invalid clustering structure by using "falsepreserving" property of energy. The whole algorithm traverses every branch of every layer to identify the final effective clustering and get more reasonable number of clusters, sub-clusters shape. Figure 3 is the quotient space structure when identify effective clusters (3, 4, 5 are the final cluster nodes, the other nodes are invalid or pruned). The algorithm flow chart is shown in Fig. 4.

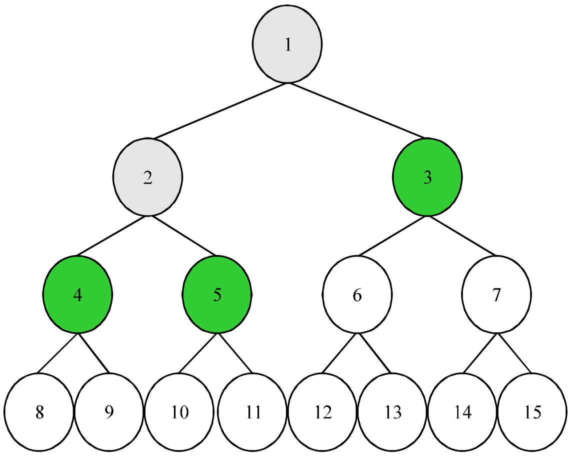

Fig. 3: Structure after clustering

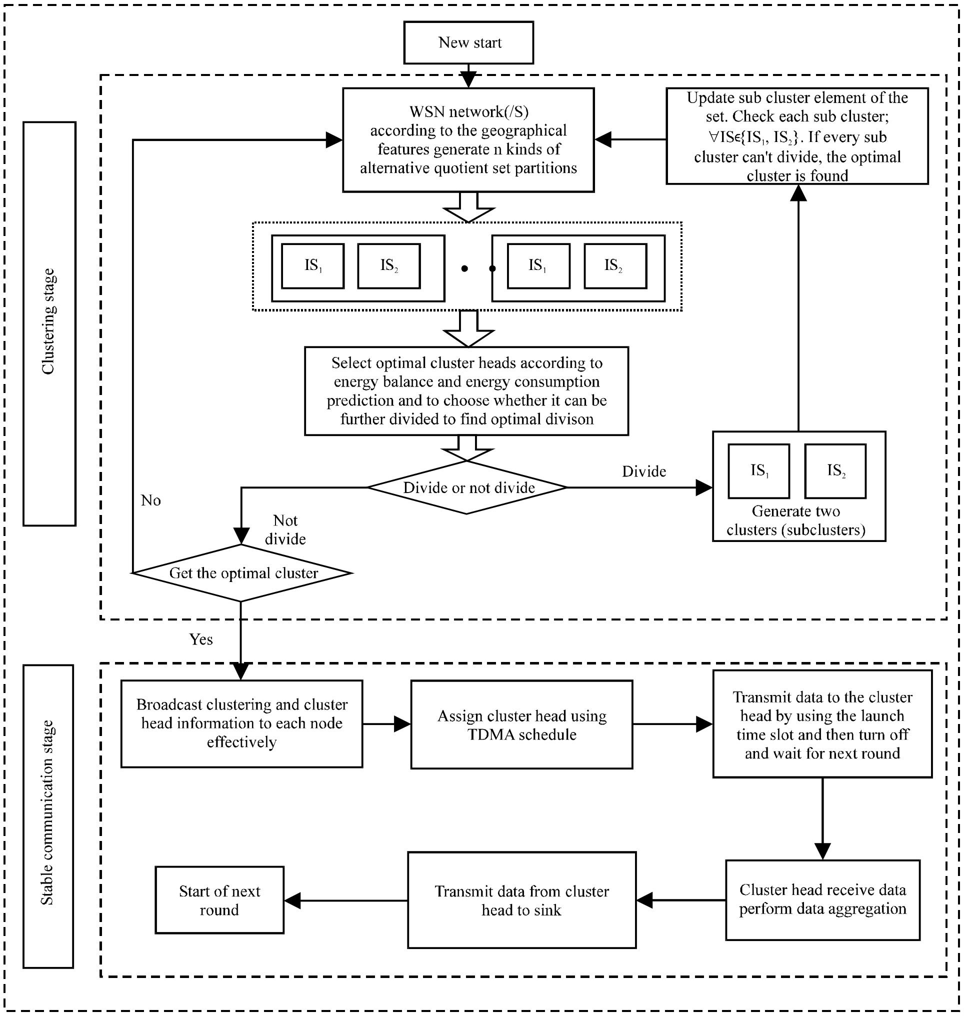

Fig. 4: Workflow of dynamic grid routing algorithm based on quotient space for WSNs (QSRA)

In general, the whole process includes establishing cluster routing stage and data transmission stage. The establishment of clustering routing is mainly for clusters division, cluster head selection, determining the final effective clustering by energy evaluation, the data transmission for intra-cluster messages broadcasting and data transmission which sent data to the SINK.

EXPERIMENTAL RESULTS

QSRA and virtual grid cluster routing methods (four grid, nine grid and sixteen grid) are used for comparison. Matlab is used for simulation and implementation of routing methods for comparison with QSRA. It proves that QSRA provides the optimal number and shape of cluster, furthermore, the network life is improved as compared to other methods. Main indicators of experiment are shown in Table 3.

We can observe from Fig. 5 and 6 that in the same round, QSRA has more live nodes during network life and QSRA has the longest network lifetime in the four methods. In Fig. 7 and 8, the energy consumption of other methods is the quickest while the energy consumption of QSRA is the lowest. In the same round, residual energy of QSRA is more than other methods, so it shows less energy consumption of QSRA for the same network and number of nodes. Obviously, QSRA is efficient as compared to other methods.

Table 4 shows the detail energy consumption and network lifetime comparisons of four routing methods. From Table 4, we can observe four routing methods of the round where, 1st node dead and the maximum round of network, SINK (100,250) experiment as an example, we can observe that the round where 1st node dead of QSRA is 368, as compared to other methods, four grid, nine grid and sixteen grid, the energy efficiency is 424, 374 and 252, respectively:

$$\text{Improved (\%)} = \frac{\sum_{i=1}^{3} (\text{QSRA} - A_i) \Big/ 3}{\text{QSRA}} \times 100$$

where, A_i is the compared algorithm.

Using this formula, we can calculate that the round where 1st node dead of QSRA improved 4.9%. Also we can observe that the maximum round of network is 1343 as compared to other methods (Four grid, Nine grid and Sixteen grid) and the energy efficiency is 1198, 1317, 1313, respectively. The maximum round of network improved 4.99%.

Similarly, when position of SINK (100,350), the round where 1st node dead of QSRA improved 37.86%, the maximum round of network improved 8.04%. So, QSRA is better for the two indicators. This proposed method has the longest lifetime as compared to other methods, four grids, nine grids and sixteen grids.

QSRA considers balanced energy consumption and geographical distribution which can save more energy and extend the lifetime of WSN as shown in experimental results as compared to other routing methods.

Table 3: Main technical indicators for comparison

Technical indicator	Value
Base station location	(100,250), (100,350)
Monitoring area	200 m×200 m
Network nodes	300
Initial node's energy	0.5J
Data packet length	4000 bit
Control packet length	100 bit
Energy consumption of transmission	50×10-9 J bit^{-1}
Energy consumption of receive data	50×10-9 J bit^{-1}
Energy consumption of data fusion	5×10-9 J bit^{-1}
Energy consumption of transmitter	1×10-11 J bit^{-1}
Energy consumption of amplifier	1.3×10-15 J bit^{-1}

Table 4: Energy consumption and network lifetime comparisons of four routing methods

	Virtual grid cluster routing			
Simulation scenarios	Four	Nine	Sixteen	QSRA
Scenario 1 SINK (100,250)				
Total energy	150J	150 J	150 J	150J
Round where 1st node dead	424	374	252	368
Maximum round of network	1198	1317	1313	1343
Scenario 2 SINK (100,350)				
Total energy	150J	150J	150J	150J
Round where 1st node dead	244	142	95	258
Maximum round of network	897	836	805	920

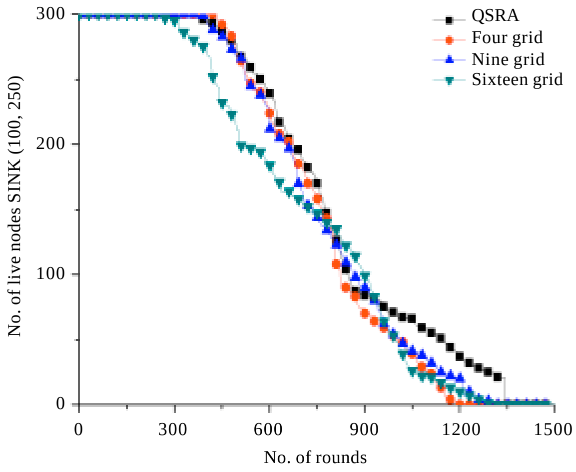

Fig. 5: Network life of four routing methods-SINK (100, 250)

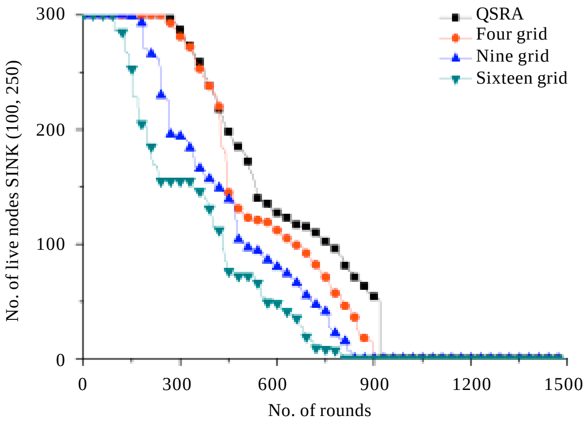

Fig. 6: Network life of four routing methods-SINK (100, 350)

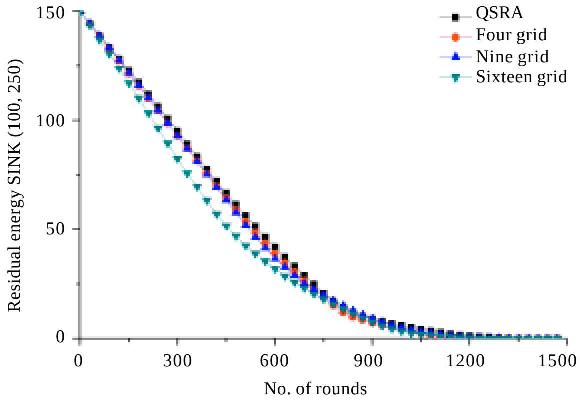

Fig. 7: Residual energy of four routing methods-SINK (100, 250)

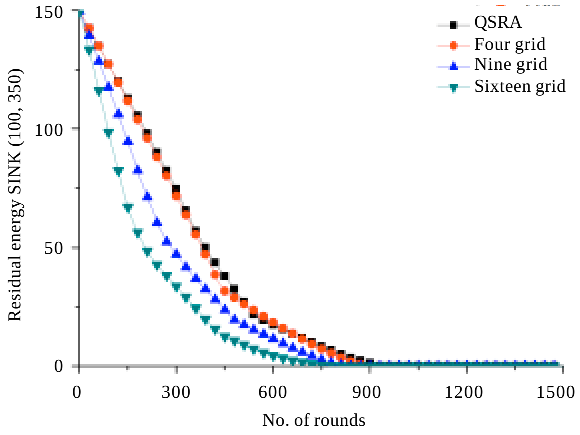

Fig. 8: Residual energy of four routing methods-SINK (100, 350)

CONCLUSION

In this study, related literature about clustering protocol has been reviewed and a comprehensive analysis is performed. The analysis and limitations of existing clustering algorithms are identified. To address these limitations, WSN Information system based on Quotient Space theory has been created and a dynamic grid routing algorithm based on Quotient Space (QSRA) for WSN is proposed. QSRA can consider geographical distribution of sensor nodes automatically while energy consumption calculation is done dynamically to determine the actual number and distribution of regional clustering. Simulation results show remarkable improvement in network life time and cluster distribution.

This study is the first to use the Quotient Space Granular Computing in a WSN clustering protocols and put forward a new research direction. Future study will mainly focus on heterogeneous nodes, equivalent relation, more optimal division of granularity, hierarchical multi-hop routing algorithm.

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