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QoS Oriented and Energy Efficient Routing Protocol for Cooperative MIMO Based Mobile WSN: Q-E2RPC

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Abstract

In this paper, a robust mobility assisted WSN routing protocol named QoS oriented and Energy Efficient Routing Protocol for Cooperative Multiple Input Multiple Output (MIMO) based mobile WSNs (Q-E2RPC) has been developed that exploits the efficiency of network partitioning, Fuzzy Clustering Mean (FCM) and Expectation Maximization (EM) based clustering, Fuzzy Logic Controller (FLC) based Cluster Head (CH) selection and mobile sink based data gathering to meet QoS demands and energy efficiency. Unlike classical clustering methods FCM and EM as a cumulative solution enables optimal clustering, which is followed by the multiple network parameters based CH selection. The use of single mobile sink avoided multi-hop transmission and signaling overheads that eventually reduced energy consumption. Q-E2RPC protocol exhibited timely data delivery, low energy consumption, and reduced signaling overheads. The results exhibited that Q-E2RPC outperforms other state-of-art techniques in terms of higher throughput, low delay and energy consumption, and higher network efficacy.

Keywords: Wireless Sensor Networks; Cooperative MIMO; Fuzzy Logic Controller; Expectation Maximization.

1. Introduction

Wireless sensor network (WSN) has emerged as one of the most efficient network solutions. The robustness of WSN makes it suitable for being used in major applications, including healthcare, civil surveillance, defense systems, industrial monitoring and control, business communication, traffic surveillance and control, and critical data sensing and control [1]. WSN has gained significant attention to enable low cost communication solution for Internet of Things (IoT) ecosystem, primarily in Low Power Lossy Network (LLNs) [2]. To fulfill quality of service (QoS) demands and energy efficient communication, numerous efforts have been made [3-6], where emphasis is made on achieving higher bandwidth utilization, minimal end-to-end delay, minimum data loss and energy consumption, reliable communication etc. However, limited energy and continuous sensory communication forces WSN to undergo exhaustion and network or node-dead condition. Among major solutions cooperative communication has been found potential to support efficient routing. Sharing of real time network statistics among the connected nodes (CNs) helps in better routing decision. To assist energy and resource efficient communication, Multiple-Input Multiple-Output (MIMO) technique is found potential [7]. It plays vital role in alleviating the key issues of low transmission rates and low reliability. Since, the lifetime of each sensor node primarily relies on its battery capacity; WSNs require dealing with energy exhaustion issues. Constructing WSN nodes having multiple antennas could be difficult because of the size and complexity related constraints.

To deal with this situation, WSNs can apply MIMO in cooperative way that can assure reliable communication but also energy efficient transmission over defined network region. In CMIMO multiple nodes construct transmission and receiving clusters by performing synchronization and synchronize data exchange to ensure that the clusters could apply standard MIMO for communication. CMIMO exploits the cooperative nature of the densely deployed nodes to ensure reliable communication. It intends to reduce energy consumption and delay while enabling higher throughput at the receiver to meet QoS provision. CMIMO using multiple sensor nodes functional in cooperative manner makes communication more efficient. In this technique, multiple sensor nodes are physically connected or clustered to perform communication, where within a cluster, sensor nodes communicate with relatively low power than to inter-group communication. MIMO system also requires performing early (i.e., delay sensitive) data gathering to alleviate the issue of redundancy and energy exhaustion. Typically, data redundancy is caused because of relaying the signal to nearby users working as the intermediate nodes. CMIMO for WSN discriminates itself in terms of data redundancy from user CMIMO systems [8-10]. Clustering based WSN routing protocol encompasses node grouping and CH selection, which is performed in such a manner that the non-CH nodes could communicate with connected CH directly. In CMIMO based WSN, CH forwards gathered data to the sink directly or in multi-hop paradigm. Thus, the groups of CHs constitute a connected dominating set. However, factors like the optimal number of clusters, optimal CH selection, and transmission play decisive role in WSN performance. Unlike generic multi-hop transmission

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based WSNs, the use of a single mobile sink can avoid unwanted retransmission and hence can assure higher throughput, low energy consumption and delay. With this motivation, in this paper the emphasis is made on applying an enhanced grid partitioning, hybrid (or dual phase) clustering, multi-parameters (distance, RSSI, responsiveness) based CH selection, cooperative MIMO based transmission, and mobile sink based data collection to meet QoS demands and energy efficient communication over WSNs. The results obtained have exhibited that the proposed QoS Oriented Energy Efficient Routing Protocol for CMIMO based Mobile-WSN (Q-E2RPC) outperforms existing state of art techniques.

Considering the significance of QoS oriented and energy efficient WSN routing protocol, this study intends to incorporate a multi-objective optimization measure to improve node clustering, CH selection, and data transmission. Q-E2RPC model exploits both FCM and EM based two-phased clustering, FLC based CH selection, CMIMO based transmission and single mobile sink based data collection. Our overall research effort intends to retrieve answers for the following questions Guidelines:

1. *Can multiple network parameters (i.e., residual energy, link quality or SNR, distance, node responsiveness etc) as cumulative network statistics be significant to enable efficient CH selection?*
2. *Can the use of soft computing algorithm such as Fuzzy Logic Controller be efficient to perform clustering and CH selection?*
3. *Can fuzzy logic be significant to perform multiple network parameter based CH selection to assist CMIMO based transmission over WSNs?*
4. *Can Expectation Maximization approach be efficient to strengthen FCM based clustering to achieve reliable and efficient communication over large scale WSNs?*
5. *Can the use of Mobile Sink be a plus to assist timely and energy efficient communication over CMIMO based WSNs?*
6. *Can the above mentioned contributions (1-5) be effective to enable a QoS oriented and energy efficient routing protocol for WSNs?*

The list of abbreviations and respective definition is given in Table 1.

Table 1. List of Abbreviation

Abbreviation	Definition
QoS	Quality of Service
MIMO	Multiple Input Multiple Output
Q-E2RPC	QoS oriented and Energy Efficient Routing Protocol for Cooperative Multiple Input Multiple Output (MIMO) based mobile WSNs
WSNs	Wireless Sensor Networks
FCM	Fuzzy Clustering Mean
FLC	Fuzzy logic controller
EM	Expectation Maximization
CH	Cluster Head
IoT	Internet of Things
LLNs	Low Power Lossy Network
CNs	connected nodes
CMIMO	Cooperative Multiple Input Multiple Output
RSSI	Received Signal Strength Indicator
LEACH	Low-Energy Adaptive Clustering Hierarchy
MAC	medium access control
EE-LEACH	energy-efficient LEACH
MCMIMO	Multi-Channel CMIMO
VMIMO	Virtual MIMO
CCP	Cooperative Clustering Protocol
2D	Two dimensional
SIMO	Single Input Multiple Output
MISO	Multiple Input Single Output
STBC	Space-Time Block Coding
CH-C-TEEM	CH Cooperative Trustworthy Energy Efficient MIMO
EBCS	Energy Based Clustering Self organizing map
EMHR-FL	Multi-hop Hierarchical Routing Protocol using Fuzzy Logic
FIS	Fuzzy Logic Inference System
SNR	Signal to Noise Ratio
CSI	Channel State Information
CM	Covariance Matrix
DoD	Degree of Dependence
CoG	Center of Gravity
TSP	Traveling Salesman Problem
DTR	Data Transmission Request

2. Related Work

This section primarily discusses some of the key literatures presenting WSN routing protocol, particularly using CMIMO technique. He et al. [11] developed CMIMO model by applying clusters of different sizes. Authors found that with clusters of the same size, CH with relatively lower residual energy might undergo fast energy exhaustion than the one with more residual energy. This as a result may provoke re-clustering iteratively for CH selection and therefore may consume more energy. To deal with it, authors applied the trade-off between residual energy of CH and the size of cluster. Heinzelman et al. [12] developed Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol by combining energy-efficient clustering and medium access control (MAC). Qin et al. [13] proposed energy-efficient LEACH (EE-LEACH) and CMIMO where EE-LEACH performed network partitioning into fixed regions having equal angle that avoided the possibility of non-uniform CH distribution. In their approach, authors applied node location and the residual energy for CH selection. Singh.D et al. [14] proposed Enhanced Modified LEACH (EMODLEACH) protocol for WSN. Where the network can be classified into proactive, reactive and hybrid networks. Xiong et al. [15] applied network coding for an energy efficient CMIMO transmission and found that network coding reduces delay and energy consumption during inter-cluster communication. Singh.D et al. [16-17] proposed an improved energy routing protocol (IBRP) is an advanced version of LEACH protocol.in WSN. Fei et al. [18] exploited CMIMO and cluster based WSN to perform energy efficient communication. Authors found that the number of nodes involved in CMIMO based communication doesn't vary with the number of nodes having data for transmission. A distributed MIMO-adaptive energy-efficient clustering model was developed by Siam et al. [19] where authors applied multi-hop transmission. However, multi-hop retransmission caused energy exhaustion could not be addressed. Islam et al. [20] developed a channel condition aware CH selection and energy efficient CMIMO for WSNs. Cheng et al. [21] applied single-hop transmission and CMIMO to achieve energy efficient communication.

Cui et al. [22] applied CMIMO by using multiple sensor nodes in the same cluster to perform cooperative communication. Authors stated that for inter-cluster communication there is no need of local information exchange where the nodes can communicate using Alamouti diversity codes. Gao et al. [23] developed a load-balanced cluster-based CMIMO transmission for WSN. Authors derived a two-layer hierarchy clustering model in which CH collects data using CMIMO communication. CMIMO was also used by Pillutla et al. [24] where they focused on the optimizing energy consumption and transmission rate. To achieve it authors developed a provably convergent block coordinate descent algorithm that estimates the rate and the number of clusters. Li et al. [25] explored CMIMO to perform inter-cluster and intra-cluster communication to preserve energy consumption. A similar effort was made by Chaibrassou et al. [26] where they applied a weighted link function to assist CH for cooperative nodes selection for data forwarding. They [27] developed a distributed Multi Channel CMIMO routing model for cluster based WSNs (MCMIMO) that at first organizes nodes into clusters and then the CH exploits weighted link function to identify the best cooperative nodes for data transmission. Nguyen et al. [28] applied Virtual MIMO (VMIMO) concept to derive a distributed Cooperative Clustering Protocol (CCP), where they used VMIMO diversity gain by performing CN selection within each cluster. Sharmila et al. [29] used the relationship between the data generated by each node and the distance between them to perform clustering. Applying CMIMO and data aggregation techniques authors derived energy efficient WSN routing protocol. Jaafar et al. [30] applied distributed space-time coding technique based multi-hop VMIMO for WSNs. Jayaweera et al. [31] applied multiplexing gain of VMIMO to obtain energy efficient and low overhead routing in WSN. Yuan et al. [32] applied cluster-based CMIMO to alleviate the impacts caused due to the radio irregularity and fading in multi-hop transmission. Malleswari et al. [33] and Mamun et al. [34] developed a cluster-based VMIMO for energy-constrained WSN communication. Authors applied Space-Time Block Coding (STBC) based VMIMO in conjunction with LEACH to achieve energy efficient routing. Sachan et al. [35] examined the impact of distance and long range distances on the selection of MIMO, MISO, SIMO, and SISO. Tiwari et al. [36] developed VMIMO for energy-efficient WSNs using an analytical approach. Wang et al. in [37] applied a clustered WSN in which nodes were distributed randomly within a circle area around single CH at the center. Once CH broadcasts source message to the neighboring nodes, those neighboring nodes which have successfully decoded the message were used to relay data towards sink using STBC to construct VMIMO. Ding et al. [38] developed a cluster-based VMIMO technique for energy-constrained WSN communication. Xu et al. [39] developed VMIMO coupled with multi-hop transmission, where a cross-layer model was derived using transmission rate, clusters and the virtual antenna nodes. Medhia et al. [40] applied mobility and CMIMO for WSN. To enable CMIMO communication each mobile node applied Alamouti diversity algorithm. The mobile sensor could move to a defined network location to collect sensed data and transmit it to the sink using CMIMO [41]. However, their approach lacked proactive node management that could have made it more realizable for real time system. Vidhya et al. [42] extended LEACH and used multi-hop transmissions to derive a cluster-based CMIMO for WSN. Cui et al. [43] examined CMIMO with Alamouti code for single-hop transmissions over WSN. Jayaweera et al. [44] examined CMIMO efficiency in terms of energy consumption and training overhead, where they found that CMIMO outperforms SISO-based WSNs. Sathian et al. [45] applied game theory to derive a CH Cooperative Trustworthy Energy Efficient MIMO (CH-C-TEEM) routing protocol. Islam et al. [46] developed cooperative communication approach, where the selected sensors at the transmitter form a MIMO. In their approach, the selection of nodes at the transmitter was done using the network parameters such as channel condition, residual energy; inter node distance and location. Zhang et al. [47] derived a cooperative node selection model for WSN under energy-constrained scenarios. Authors combined the residual energy and the link quality between the CHs to perform data transmission. Chattha [48] developed an energy balancing intelligent clustering model based MIMO which was applied in conjunction with the optimal forwarding/receiving node selection. Authors [49] derived a cluster size optimization model using the concept of the spatially correlation in data. Authors [50] focused on balancing the energy consumption between CHs. The underlying principle behind the work in was that CHs near the sink require relaying more traffic than outsider CHs and therefore undergoes high energy depletion. Energy Based Clustering Self organizing map (EBCS) based clustering was developed by Enami et al. [51]. Amri et al. [52] developed a Multi-hop Hierarchical Routing Protocol using Fuzzy Logic (EMHR-FL), where Fuzzy Logic Inference System (FIS) was used to perform next-hop selection by considering residual energy of CHs, distance between CHs and node density. Kubo et al. [53] performed multiple cooperative nodes selection by using “quality” and “angle” metrics.

3. Problem formulation

As discussed in previous section, a few efforts have been made to exploit the efficacy of enhanced clustering, better CH selection and CMIMO to enable energy efficient communication over WSNs. Most of the existing approaches either apply single parameter like residual energy, distance or link quality for CH selection. The reliability of such approaches often remains questionable, especially when a node undergoes mobility and hence dynamic topological conditions. On contrary, introducing mobile sink in clustering based WSN can enhance overall communication efficiency by avoiding multi-hop transmission that consumes significant energy during multi-node traversal and retransmission. Additionally, it can be vital for time efficient data gathering for QoS provision. In clustering based routing, the efficiency of clustering and CH selection often play vital role. Therefore, enhancing clustering and CH selection by exploiting key network variables such as inter-node distance, degree of dependence, etc can be significant. Furthermore, the use of multiple network parameters for CH selection can also be a revitalizing effort. In major existing system classical peer to peer transmission model is applied that reserves bandwidth for predefined node data transmission. It affects overall resource utilization efficiency of the routing protocol. Additionally, multi-hop transmission imposes significant retransmission and signaling overhead that leads energy exhaustion. To alleviate these issues CMIMO transmission can be a potential approach. In addition, the use of a single mobile sink to collect sensed data from CHs and CNs can also make overall routing protocol delay and energy efficient.

Considering large scale network, unlike classical clustering, in our routing protocol at first a large scale network is split into groups, which is then followed by clustering in each group. In Q-E2RPC routing protocol a hybrid clustering approach having dual phase implementation is developed, where in first phase FCM algorithm is applied that exploits inter-node distance to cluster nodes. In the second phase, an enhanced EM model is applied that exploits degree of dependence of a node on cluster to perform final clustering, before executing CH selection. This combined model ensures optimal number of clusters in the network that eventually reduces energy exhaustion and signaling overheads. Furthermore, considering significance of CH selection in WSN, the use of multiple network parameters can be vital. In CH selection model, node information, residual energy, Signal to Noise Ratio (SNR) or RSSI and node responsiveness are taken into consideration. The use of a single parameter such as the residual energy or the distance can be easy to decide CH of a cluster; however selecting CH with multiple parameters even under dynamic topology can be a trivial task. To deal with it, Q-E2RPLC incorporates FLC that learns multiple network states to perform optimal CH selection. In practice, multi-hop transmission intends to assure reliable transmission without data loss, however at the cost of retransmission and higher energy consumption. To alleviate such issues, introducing mobile sink can be vital, where a mobile sink can collect data from the CHs directly to avoid unwanted traversal and resulting energy exhaustion. To further strengthen the mobility model certain trajectory estimation approach such as travelling salesman problem etc can also be applied. Q-E2RPC protocol exploits CMIMO transmission features to perform inter-node communication from CH to mobile sink. This as a result makes overall communication energy, delay and resource efficient.

4. Proposed System

4.1. Mobile-WSN Model

Considering real-time communication where there can be a large number of sensors distributed across the field, Q-E2RPC has been developed with dense network with multiple sensor nodes. Such communication environment can be manufacturing establishments, schools/universities, hospitals, surveillance systems, border security etc. To alleviate the probability of contention and data losses during traversal across large network, Q-E2RPL protocol splits overall network into sub-network or regions called "Group". An illustration of the applied network region is given in Fig. 1.

In Fig.1, circles presents N sensors distributed across the network with dimension L×L. Here, the solid circle C presents the CH formed, which is supposed to be visited by the mobile sink for data collection by means of CMIMO transmission scheme. The solid-fill circles refer nodes in a group, while dotted region presents the cluster. Here, the term "Group" signifies a set of nodes which are able to communicate with each other. The nodes in other groups are unable to communicate due to high inter-node distance. Let G be the total number of groups in the network and N_g and C_g be the total number of sensor nodes and the number of clusters in gth group, respectively. Unlike traditional approaches, the total number of groups is estimated by exploiting the location of the nodes and its radio range R. Here, each CN shares its information to perform CH selection. Once receiving the data from CNs, CH forwards it to the mobile sink using CMIMO transmission. In Q-E2RPC, each CH operates as the cooperative transmitter, receiving the data packet processes for encoding by means of algorithms STBC. It is then followed by the transmission to the mobile sink. In cooperative communication, the receiving CHs can use Channel State Information (CSI) to decode the STBC data and the decoded data can be relayed to the sink for further process.

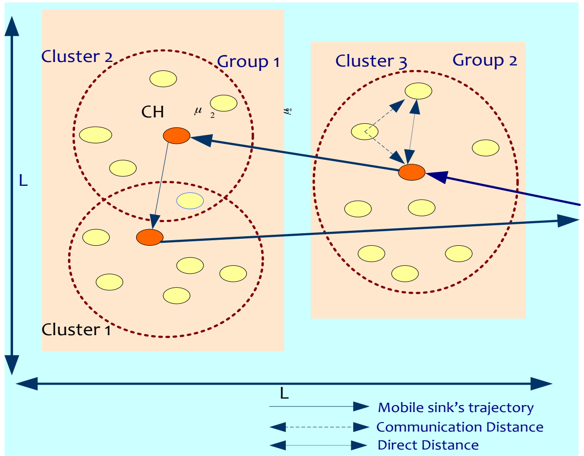


Fig.1. Mobile-WSN Network

In Q-E2RPC, it is assumed that each node is aware of its own position and cluster's location. Practically, it can be achieved through certain node positioning algorithm. Here, each node has a definite communication range R and therefore transmission can be successful only within R. Each node possesses a definite amount of memory to store sensed data to forward it to the sink. CHs collect sensed data from CNs through CMIMO transmission approach and meanwhile mobile sink collect data from CHs in the similar manner. To avoid unwanted multi-hop traversal, in Q-E2RPC a single mobile sink has been applied that assures timely data gathering to enable swift decision. It not only reduces traversal time but also reduces energy exhaustion due to (multi-hop) retransmission.

The efficiency of a clustering based WSN routing protocols depends on two key factors, clustering and CH selection. The use of real-time network parameters such as network link, radio strength, energy level and channel gain etc can make CH selection more efficient. Such hypotheses have been asserted by researcher [54] where authors applied RSSI, energy level, channel gain and distance to perform CH selection. However, applying multiple parameters to decide CH is intricate and can become more trivial under dynamic topology. To alleviate such issues, in our model FLC algorithm has been applied that learns the network parameters to perform CH selection. Here, it should be noted that in Q-E2RPC, before executing clustering and CH selection, we have executed network partitioning that splits overall network into two groups that makes overall computation efficient. Each node forwards sensed data to the connected CH via CMIMO transmission where CH further combines those data to transmit towards the destination node.

4.2.System Design

Q-E2RPC exploits the efficacy of the different enhancements made for clustering, CH selection, CMIMO transmission and mobile sink based data gathering to enable delay resilient and QoS communication over WSN. Q-E2RPC incorporates the following steps:

Step-1 Fuzzy cluster mean (FCM) and Expectation Maximization based clustering,
Step-2 Fuzzy Logic Control (FLC) based CH selection,
Step-3 Cooperative communication based data transmission using Single Mobile Sink node.
A brief of the implementation model is given as follows:

i. Dual Phase Clustering
Unlike classical clustering approaches, we have applied dual phase clustering, where at first FCM is executed to perform initial clustering over two groups. Once performing initial clustering, we have executed EM based centralized clustering that uses the cluster information and associated CNs information to re-structure the clusters. A brief of this clustering paradigm is given as follows:

1. FCM Based Initial Clustering
Once performing grouping or the network partitioning, FCM [55] is executed that exploits inter-node distances to perform initial clustering. Typically, FCM is used to perform pattern recognition by providing membership to each data point related to each cluster center, where the summation of membership for all data points should be equal to one. In FCM based clustering we intend to minimize an objective function given in (1).

$$\min_{\mu_{ij},m_j}(v_q), \tag{1}$$

Where

$$v_q = \sum_{i=1}^{N}\sum_{j=1}^{M}\mu_{ij}^{q}\left\|\theta_i - m_j\right\|^2, \tag{2}$$

Noticeably, the deployed WSN network considers node distribution in such manner that it depicts like a network graph G, with each vertex signifying the node's position in 2D space. Mathematically, sensor node is positioned as $q_i = [X_i, Y_i]^T$ for the ith node. Thus, in above equation, q_i signifies the location parameter of a node. If the two nodes i and j are located within their communication or radio ranger, their link could be defined in terms of an edge. In (2) M states the total number of clusters, q presents the fuzziness exponent (>1), μ_{ij} presents the degree of membership of ith node in jth cluster and m_j states the center of cluster j and m_k refers center of cluster k. The value of μ_{ij} exists in the range of 0 to 1 for each CN to the CH. Here, we have performed fuzzy partitioning by means of an iterative optimization scheme where it intends to minimize the objective function given in μ_{ij} (3).

$$\mu_{ij} = \frac{1}{\sum_{h=1}^{M}\left(\frac{\|\theta_i - m_j\|}{\|\theta_i - m_k\|}\right)^{\frac{2}{q-1}}}, \tag{3}$$

Finally the cluster center m_j obtained is (4).

$$m_j = \frac{\sum_{i=1}^{N}\mu_{ij}^{q}.\theta_i}{\sum_{i=1}^{N}\mu_{ij}^{q}}. \tag{4}$$

Once reaching stopping criteria the iterative optimization is stopped. Noticeably, in FCM based clustering the stopping criteria is defined as

$$\{\mu_{ij}^{k+1} - \mu_{ij}^{k}\} < \sigma,$$

Where, k signifies the iteration step.

The snippet of the applied FCM based clustering is given as follows (Fig. 2):

Algorithm-1 FCM based Clustering
Initialization: membership values $\mu_{i.j}$ $\forall h = 1, 2, ..M$ $\forall i = 1, 2, ...N$
Cluster Centers Initialized
while $\{\mu_{ij}^{k+1} - \mu_{ij}^{k}\} < \sigma$ ***do***
for $j = 1, 2, ...M$ ***do***
$m_j = \frac{\sum_{i=1}^{N}\mu_{ij}^{q}.\theta_i}{\sum_{i=1}^{N}\mu_{ij}^{q}}$
end for
for $i = 1, 2, ..N$ ***do***
for $j = 1, 2, ..M$ ***do***
which is μ_{ij}^{k}
if $\|\theta_i - m_j\| > 0$ ***then***
Calculate μ_{ij} as
$\mu_{ij} = \frac{1}{\sum_{h=1}^{M}\left(\frac{\|\theta_i - m_j\|}{\|\theta_i - m_k\|}\right)^{\frac{2}{q-1}}}$
which is μ_{ij}^{k+1}
end if
end for
end for
end while

Fig. 2 FCM based clustering

To further strengthen clustering, a centralized clustering approach named EM has been applied.

2. Expectation Maximization Based Clustering
EM is a generic clustering model that assumes that all sensor nodes are distributed as per Gaussian Mixture Model (GMM) (5).

$$E(x) = \sum_{c=1}^{C}\pi_c A(x|\sigma_c, \Sigma_c) \tag{5}$$

In (5), variables C and σ_c present total clusters and a combination factor for the cth cluster, respectively. Here, $A(x|\sigma, \Sigma)$ is obtained using (6).

$$A(x|\sigma, \Sigma) = \frac{1}{(2\pi)|\Sigma|^{1/2}} exp\left\{-\frac{1}{2}(x-\sigma)^T\Sigma^{-1}(x-\sigma)\right\}, \tag{6}$$

In (6), x and σ signify the location vector of CNs and the location vector of CH of the cth cluster, respectively. The variable Σ_c states a 2×2 Covariance Matrix (CM) of the cth cluster. Unlike FCM, EM calculates Degree of Dependence (DoD) of each CN that is nothing else but the Responsiveness of a node on the connected cluster. We have estimated "Responsiveness" of a node n on kth cluster using (7).

$$\varphi_{nc} = \frac{\pi_C A(x_n|\sigma_C, \Sigma_C)}{\sum_{j=1}^{C}\sigma_j A(x_n|\sigma_j, \Sigma_j)}. \tag{7}$$

Typically, the value of responsiveness (7) remains in the range of 0 and 1.

Once performing FCM based initial clustering and retrieving the location vector of the CHs, the communication distances D_{nc} between each CN and associated CH is estimated. In this way, two components location vector (σ) and covariance matrix (Σ) are obtained. Now, to deal with the complexity due to the large size (i.e., dense) network, the overall network is partitioned into groups. Once initiating the EEM based clustering phase, the proposed Q-E2PRC model selects a particular group with the highest value of the proportion of the number of residing nodes to the total cluster counts in group g. In other words Q-E2PRC routing protocol selects a group with the highest value of the parameter v_g, which is mathematically obtained by (8).

$$v_g = \frac{C_g}{N_g} \tag{8}$$

In (8), C_g states the number of clusters in the group and N_g states the total number of nodes in the group. Thus, in the selected group having the highest value of v_g, Q-E2PRC model selects all those nodes which belong to the group g and updates the node responsibility factor, φ_{nc} for these all nodes. In our proposed routing model the value of φ_{nc} signifies the extent to which a node n belongs to the cluster k. Thus, employing the updated responsibility factor, φ_{nc} the cluster centroids, and covariance matrix are re-estimated and the total number of nodes belonging to the kth cluster is obtained using (9).

$$N_C = \sum_{x_n \in X} \varphi_{nc} \tag{9}$$

Thus, this process continues till the difference between newly estimated log-likelihood and the previously estimated log likelihood becomes lower than the value of ϵ.

In proposed EM based CCP model, C signifying weighted Center of Gravity (CoG) of a 2D-location vector is estimated for each node. To achieve it, the responsiveness of each node (assuming it to be the weight of the node) is considered. Later, location of the CH can also be changed by the weighted CoG. In our model EM estimates the log likelihood to estimate optimal number of clusters using (10).

$$\mathbb{L} = ln\, E(X|\sigma, \Sigma, \sigma) = \sum_{n=1}^{N} ln\{\sum_{c=1}^{C} \sigma_c A(x_n|\sigma_c, \Sigma_c)\} \tag{10}$$

Similar to the FCM based approach; EM continues iterating until convergence. The value of (10) reduces uneventfully thus making EM terminate. EM updates the key information such as, σ_c and φ_{nc} of each node to the cth cluster that eventually leads reduction in the Sum of Square (SoS) of the distance between each node and cluster. It finally gives the optimal clustering results. Once performing clustering, CH selection is performed for each cluster for which FLC is applied that learns over the network parameters to select the best node so as to become the CH for further data transmission.

ii. Cluster Head (CH) Selection

The selection of CH often plays decisive role in assuring optimal performance. With this motivation, we have applied multiple network parameters to perform CH selection. The parameters being used in our model are as follows:

- *Location information of each sensor node within the cluster,*
- *Distance of each sensor node with respect to the base station of sink location,*
- *Residual energy of each node, and*
- *SNR of the reporting channel of the CH and base station.*

Here, location information enables the selection of CH near CNs that consequently minimizes multi-hop transmission and hence energy consumption. The distance between CNs, CHs and mobile sink can affect the transmission efficiency, even with CMIMO. Hence, we perform CH selection in such manner that the distance between CNs and CH is lower enough to communicate in single-hop. Since, CH is selected near CNs and hence, the distance between CH and mobile sink might increase. Under such scenarios, the probability of link failure can't be ignored. Considering such issues, we have used SNR of the link from CH to the sink as an additional parameter for CH selection. Realizing the fact that the successful data transmission also depends on the residual energy of the forwarding node, we have used residual energy of each node to assess its suitability to become the CH of that cluster. Exploiting multiple parameters for CH selection can be an intricate task that becomes more tedious during topological variations (due to sink mobility). To deal with this, we have applied FLC that learns over the network parameters to decide CH for each cluster. In our model, we have applied four key network parameters including distance (i.e., node position), residual energy, SNR and responsiveness to decide optimal CH for a cluster. The decision variables and respective conditions are presented in Table 2.

Table 2. CH Selection Conditions

Parameters	Suitability
Distance	Low
Residual Energy	High
SNR	High
Responsiveness	High

FLC model learns over the network parameters and intends to achieve a defined objective function. To select CH of mth cluster, an exclusive objective function is derived (11).

$$\Psi_i^{(m)} = \max_{CH}\left(\frac{\mho_i^{(m)}\gamma_i^{(m)}\varphi_i^{(m)}}{\alpha PL_i^{(m)} + (1-\alpha)PL_{MS}^{(m)}}\right) \tag{11}$$

Where $\mho_i^{(m)}$ presents the residual energy of ith sensor (i.e., CN), $\gamma_i^{(m)}$ signifies the SNR of the link between the ith node and the sink, and $\varphi_i^{(m)}$ refers the responsiveness of ith node. The other parameter $PL_i^{(m)}$ presents the average path loss of the channels between the ith node and the other CNs. The variable $PL_{MS}^{(m)}$ refers path loss of ith CN and sink, and α presents a weight parameter assigned to the path loss components $PL_i^{(m)}$ and $PL_{MS}^{(m)}$, i.e., CN to CH and CH to the mobile sink, respectively. In (11) the value of α exists in between 0 and 1. The distances between nodes are also maintained low between possible CH and CNs. We have estimated the path loss $PL_i^{(m)}$ using (12).

$$PL_i^{(m)} = \frac{\sum_{i=1}^{N_m} PL_{i,j}^{(m)}}{N_m} \tag{12}$$

Where N_m presents the total number of sensor nodes in the mth cluster. The path loss between the ith sensor and CNs (i.e., ith sensor) is given by $PL_{i,j}^{(m)}$. Mathematically,

$$PL_{i,j}^{(m)} = 10\, n\, log_{10}\left(R_{i,j}^{(m)}\right) \tag{13}$$

In (13), $\left(R_{i,j}^{(m)}\right) = \left\|\theta_j^{(m)} - \theta_i^{(m)}\right\|$ gives the distance between jth CN and ith CH, where the position of the ith CH is $\theta_i^{(m)} = \{x_i^{(m)}, y_i^{(m)}\}$ and the position of the jth node is $\theta_j^{(m)} = \left\{x_j^{(m)}, y_j^{(m)}\right\}$. The variable n presents the path loss exponent. The path loss between CH of mth cluster and sink is obtained as (14)

$$PL_{MS}^{(m)} = 10\, n\, log_{10}\left(R_{MS}^{(m)}\right), \tag{14}$$

Where $R_{MS}^{(m)} = \left\|\theta_i^{(m)} - \theta_{MS}\right\|$, with $\theta_{MS} = \{x_{ms}, y_{ms}\}$ as the mobile sink location. Estimating network parameter, FLC is executed that performs CH selection. The CH selection algorithm is given as follows:

Algorithm-2 FLC based CH Selection

Initialize FLC based CH selection
while $m = 1, 2, .., M$ ***do***
Selecting CH for mth Cluster
for $j = 1, 2, \ldots N_{m,i}$ ***do***
Calculate $\mho_i^{(m)}, \gamma_i^{(m)}, \varphi_i^{(m)}, PL_i^{(m)}$ *and* $PL_{MS}^{(m)}$
Execute FIS learning and classification
if $\Psi_i^{(m)} = \max_{CH}\left(\frac{\mho_i^{(m)}\gamma_i^{(m)}\varphi_i^{(m)}}{\alpha PL_i^{(m)} + (1-\alpha)PL_{MS}^{(m)}}\right)$ ***then***
mth $CH \leftarrow ith$ sensor
else
Cluster member $\leftarrow$ ith sensor
end if
end for
end while

Fig. 3 FLC based CH Selection

iii. CMIMO Based Data Transmission

Once performing clustering and CH selection, the mobile sink starts patrolling to collect data from CHs. Here, it should be noted that the mobile sink collects data from CHs where the sensor data are collected by exploiting cooperative MIMO paradigm. The use of a single mobile sink might lead a situation where it could not be able to reach CHs for data collection. In such cases the probabilities of data loss and delay can't be ignored. Additionally, as the speed of mobile node is comparatively slower than the electrical communication, enhancing movement pattern of the mobile sink remains an open challenge. To deal with this problem, heuristic approaches such as Traveling Salesman Problem (TSP) can be applied to assist sink to reach CHs for early data gathering. To collect data from CHs, we have applied MIMO technique. In Q-E2RPC protocol CHs transmit data to the mobile sink using MIMO, where to collect data; mobile sink transmits a Data Transmission Request (DTR) to the CHs that further broadcasts to the CNs. Receiving DTR response from CH, mobile sink re-sends the data transmission request which is followed by relaying data from CH to the mobile sink. One more novelty introduced in Q-E2RPC is the provision of direct communication between CNs and mobile sink. Typically, CNs transmit data to the connected CH, that then forwards it to the mobile sink; however the in-depth analysis shows the scope for further enhancement, particularly for delay efficient transmission. In Q-E2RPC, transmission is scheduled in such manner that finding mobile sink nearer than the CH, a CN can transmit sensed data to the mobile sink directly that avoids transmission delay caused during transmission through CH. To minimize energy consumption during transmission, here CNs transmits data based on the responsiveness factor. As discussed, responsiveness is estimated using parameters μ, σ, and Σ, and hence these parameters can be appended to the DTR message to be transmitted back to the mobile sink. Once deploying CNs in the network, each node exchanges its location information with all CNs in the same cluster. Since, this exchange is performed only once after sensor nodes deployment that reduces the unwanted signaling overhead. In case a node belongs to multiple clusters, it can use responsiveness factor to decide best CH to forward data. For example, in case a node has the responsiveness of φ_{n1}= 0.8 and $\varphi_{n2} = 0.2$. Once receiving DTR from CH of the cluster 1, nth node transmits 80% of data. In case it receives DTR from cluster 2, it transmits remaining 20% of data to the mobile sink through CH of the second cluster. It ensures that the data reaches to the sink reliably and timely to meet QoS demands.

Signaling Overhead Optimization

In Q-E2RPC, once reaching CH of a cluster, mobile sink transmits DTR message to invite data transmission from CH and the associated CNs. Once receiving DTR message, CNs transmits its sensor data to the CH that later forwards it to the mobile sink. CNs then broadcast DTR to the neighboring sensor nodes and it continues till CH has received it. Here, the possibility of getting DTR twice or multiple-times can't be ignored that might increase signaling overhead significantly. CN at first transmits its data and then broadcasts DTR. However, the uncontrolled broadcast might cause signaling overhead imposing excessive energy exhaustion, mainly due to unwanted redundant packet transmission. Under such conditions, reducing redundant packet transmission and DTR are must. Fig. 4 illustrates DTR caused message flooding, where it can be observed that the higher connectivity may require higher DTR messages and hence can led signaling message flooding.

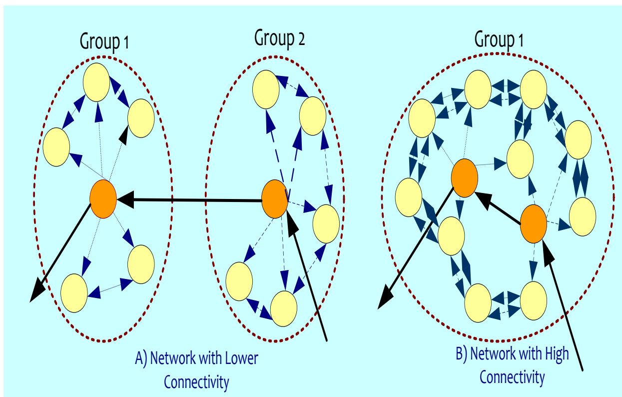


Fig. 4 Illustration of the DTR Signaling flood with different connectivity scenario

Fig. 4 illustrates WSN with two groups containing a total of 12 nodes. In the network with two CHs, the mobile sink requires traversing twice to transmit DTR to the connected CNs. It also presents that the nodes in a group can communicate only with the CNs of that group (Group-1). Mobile sink transmits DTR to each CN in cluster 1, and then each CN broadcasts transmission request. It illustrates a scenario where CNs can communicate to each other and broadcasts DTR. In this case when each node transmits DTR the total number of messages becomes higher. Though, the number of sensor nodes and CHs remains the same, the number of DTR increases with increase in connectivity. It depicts that the total number of DTR increases as per increase in the number of clusters. To reduce DTR maintaining optimal number of clusters can play a vital role. The FCM and EM based clustering assisted our model to achieve QoS oriented, energy and delay efficient communication over WSNs.

5. Results and Discussion

In this research the overall emphasis was made on developing a novel QoS oriented and energy efficient WSN routing protocol, Q-E2RPC by employing enhanced clustering approach, CH selection, cooperative communication and single mobile sink based data collection. Considering the large scale network size, at first we performed network partitioning that structured overall network into two groups. Now, realizing the significance of the optimal number of clusters in the network, a two phase clustering model was developed. In our proposed clustering method at first FCM was applied to perform initial cluster formation, which was then followed by EM based clustering. In Q-E2RPC, EM based clustering exploited initial cluster information to perform clustering, which was then followed by the use of multiple network parameters like inter-node distance, residual energy of node, signal to noise ratio and responsiveness of the node in a cluster to perform final clustering. The derived network parameter called Responsiveness factor played vital role in enabling efficient clustering that directly affects number of CHs across network. Considering multiple decision variables, we applied FLC that estimated best node as CH of each clusters. Unlike classical methods of data transmission, Q-E2RPC incorporated cooperative communication amongst CNs and associated CHs, and then CHs to the mobile sink. To alleviate the issue of excessive energy consumption (due to multi-hop MIMO transmission); we deployed a mobile sink to collect data from each CH for QoS delivery and energy efficient communication. Noticeably, in Q-E2RPC the mobile sink movement was controlled based on data request from CHs. The routing model was developed in way that it not only focuses on energy efficiency but also assures QoS delivery by maintaining minimum end-to-end delay, bandwidth utilization and higher reliability. The use of CMIMO helped Q-E2RPC to perform communication between CNs and respective CHs and CH to the mobile sink. The enhancement caused due to efficient clustering, CH selection strengthened timely data delivery, energy efficiency as well as significant reduction in computational complexity or signaling overheads. Q-E2RPC is developed over IEEE 802.15.4 MAC. The total simulation time is 800 seconds, where the transmission was tested with 2kb/sec. To assess performance of Q-E2RPC protocol, we have developed simulation model using Network Simulator tool commonly known as NS2. Further, to plot the graphs MATLAB 2015a tool was used. The simulation environment considered in this study is given in Table III.

We deployed multiple sensor nodes randomly, where a single mobile node was also deployed as sink (Node in Green color in Fig. 6). In Q-E2RPC (FCM and EM based clustering) to enable swift and efficient communication over WSN, we performed network partitioning. In Q-E2RPC, we partitioned overall network into two groups (Fig. 6). Noticeably, the connected sensor nodes of one group can communicate only with the nodes connected to it. In other words, the nodes connected to one group can't communicate with the nodes of other group (Fig. 6).

Table 3. Simulation Environment

Parameter	Value
MAC	IEEE 802.15.4
Efficiency of RF power amplifier	0.47
Link margin	40 dB
Gain factor	30 dB
Power density of AWGN channel	-134 dBm /Hz
Noise Figure (Receiver)	10 dB
Path loss	3-5
Carrier frequency	2.5 GHz
Bandwidth	20 KHz
BER performance	10-3
Transmitter circuit power consumption	98.2 mw
Receiver circuit power consumption	112.6 mw
Antenna gain of Transceiver	5 dB
Routing table update (exchange) period for each round	5
Routing table size	100
Transmission rate	2p/sec
Packet size	2 kbits
Transmission probability of each node	0.8

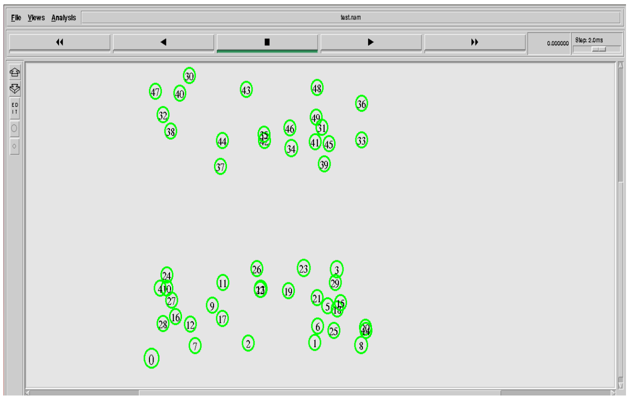


Fig. 5 Random node distribution across the WSN network

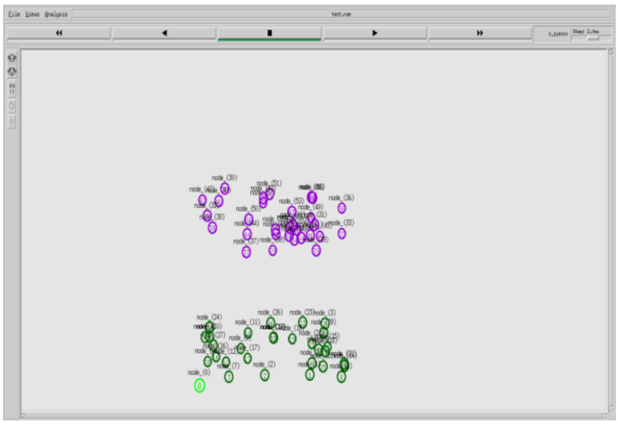
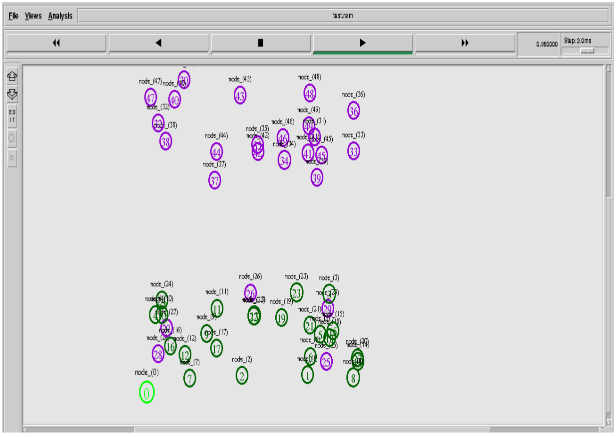
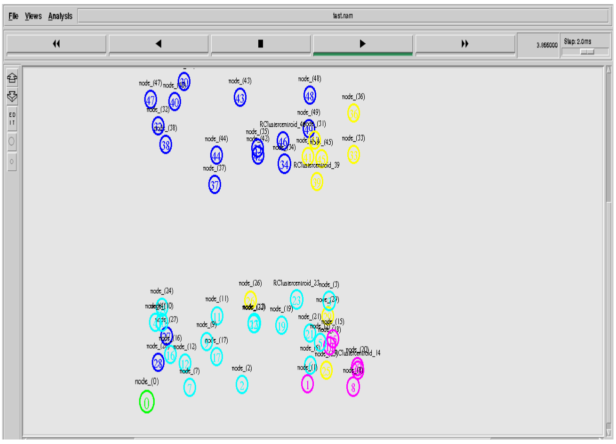


Fig. 6 Network partitioning into two groups

Once the nodes were partitioned into two groups, we executed clustering in which at first we applied FCM clustering that exploited inter-node distance to obtain initial clusters. However, realizing the need to incorporate node responsiveness to enhance clustering, we applied EM based clustering. Thus, based on the above discussed dual phase clustering we obtained the optimal number of clusters as depicted in Fig. 7. In Fig. 7, different clusters with different colors are presented. Once performing clustering, the node information including node position, signal to noise ratio, residual energy of each node and responsiveness of a node to the belonging cluster was used to perform CH selection. The CH estimated for each cluster can be visualized in Fig. 8 (black square box).



(a)



(b)

Fig. 7 (a).FCM assisted Initial Clustering, (b) .FCM+EM based clustering for Q-E2RPC routing protocol.Dual phase clustering results

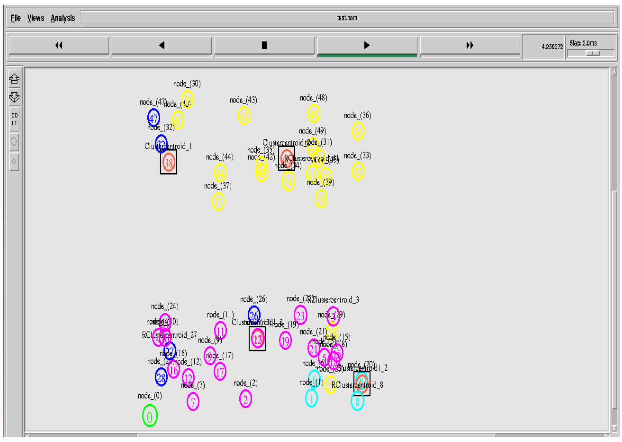


Fig. 8 FLC based CH Selection

Once performing CH selection, CMIMO transmission was applied to perform communication between CN and connected CH, which is later transmitted to the mobile sink for further decision process. A snippet of cooperative communication between CHs and mobile sink is depicted in Fig. 9.

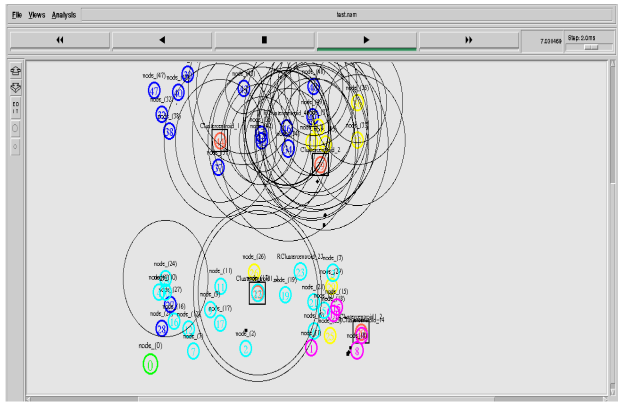


Fig. 9 Cooperative MIMO based data transmission (Mobile sink Location-1)

In Fig. 9, the initial location of mobile sink (green color) can be visualized that after certain time moves to the other location to collect data from CHs (Fig. 10). Noticeably, in Q-E2RPC nodes communicate in cooperative MIMO approach.

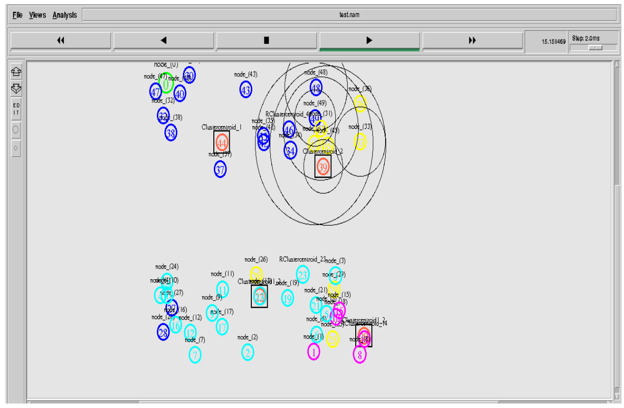


Fig. 10 Cooperative MIMO based data transmission (Mobile sink Location-2)

Noticeably, in Fig. 9 and Fig. 10, circles do signify data transmission and respective radio range. The large circles represent the radio range of the CH that reveals that the radio range of CH is sufficient enough to maintain communication with CNs belonging to that cluster.

To assess the relative performance of Q-E2RPC, we simulated FCM based clustering at first, which has been followed by FCM and EM as cumulative clustering approach. Thus, the respective performance for FCM and FCM+EM (this is the clustering model applied in our proposed Q-E2RPC routing protocol) was obtained. For CH selection we have applied FLC. The results obtained in terms of packet delivery ratio (PDR), delay, energy consumption and efficiency are given in Fig. 11, Fig. 12, Fig. 13 and Fig. 14, respectively. Observing overall results it can be found that the proposed Q-E2RPC routing protocol enables better clustering thus augmenting overall performance. Q-E2RPC performs better than FCM based clustering. Here, the effectiveness of responsiveness clustering model can be visualized. This is because responsiveness assesses connectivity and degree of dependence of a node with its cluster that assures that a node having higher connectivity with a cluster would yield more efficient communication. Mobile sink node has strengthened Q-E2RPC to exhibit delay efficient communication. Non-deniably, CMIMO based communication among CNs and CH and further between CHs to mobile sink has further strengthened energy efficiency and higher throughput. As depicted in the results (Fig. 11 to Fig. 14), FCM refers simulation outcome with only FCM based clustering. In addition to it, we have developed a multi-hop transmission by exploiting K-Conid [56] based clustering, which comes under the category of centralized clustering method. Here, it should be noted that in all these simulations, we have applied FLC based CH selection and MIMO based transmission.

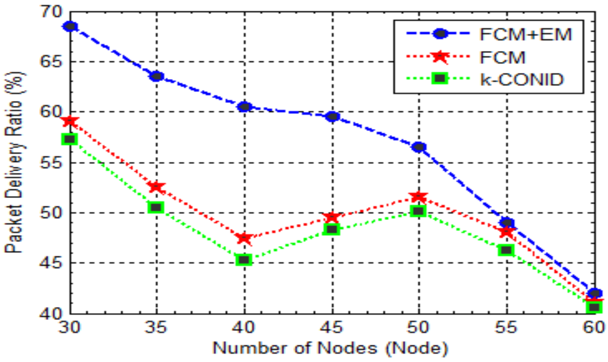


Fig. 11 Packet delivery ratio

Observing results, it can be found that Q-E2RPC outperforms both FCM and K-Conid clustering based routing. Fig. 11 presents the comparison of PDR between Q-E2RPC and FCM. The efficiency of FCM and EM for clustering optimization (i.e., maintaining optimal number of cluster to avoid energy consumption while assuring higher throughput and connectivity) can be visualized in Fig. 11. Fig. 12 shows delay of all three simulation scenarios, where Q-E2RPC has shown minimum delay. In achieving such augmented results role of mobile sink can't ignored. Its impact can be seen in Fig. 13 and Fig. 14. Considering residual energy as one of the key decisive factor for success MIMO transmission, we estimated the energy consumed, E_{Trans}during transmission from sensor nodes to the mobile sink. Here, E_{Trans} states the energy required to transmit data from the sensor nodes to the mobile sink. If a sensor node is far away from its associated CH, $E_{Dat}$is assigned a value 0. In practice, $E_{Trans} = 0$ signifies inefficiency of the clustering method and hence can't assure energy conservation or even successful transmission. Considering it as a key motivation, we derived a performance parameter called "Efficiency", which was estimated using, given in (15).

$$Efficiency = \frac{(Number\ of\ connected\ node)}{E_{Trans}} \qquad (15)$$

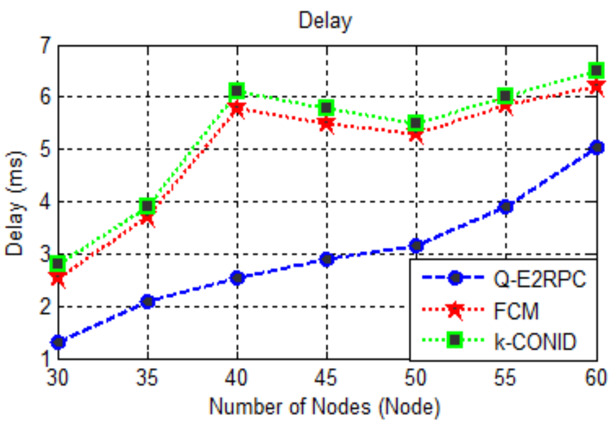


Fig. 12 Transmission or data gathering delay

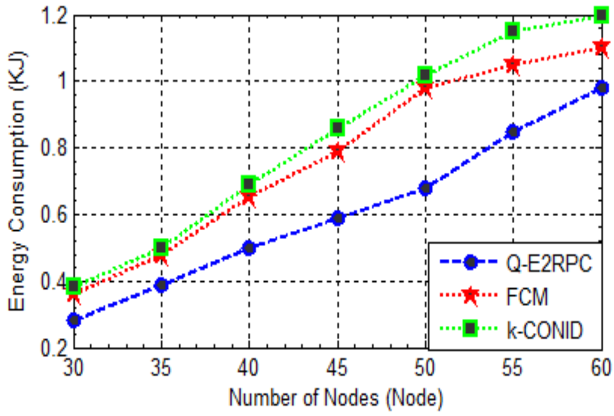


Fig. 13 Energy consumption by different techniques

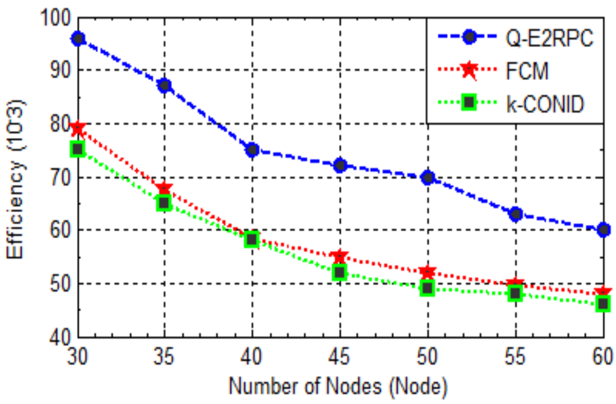


Fig. 14 Network communication efficiency

Research Question Reasoning

Recalling the research questionnaires (Section III) and the results obtained it can be easily observed that the use of multiple network parameters such as, residual energy, link quality or SNR, distance, and node responsiveness can play vital role in the optimal CH selection. Undeniably, some of the node parameters change over simulation period (For Example, signal to noise ratio vary over channel conditions, mobility too can vary network topology and hence inter-node distance). Therefore the use of these parameters for CH selection can strengthen fault resilient CH selection. This can lead reliable transmission over WSN. This research work also exhibited that the use of FLC can perform better to learn multiple parameters and can help in deciding swift CH selection. Exploring initial phase of clustering the use of FCM in conjunction of EM has enabled optimal clustering. This can be due to the use of responsiveness or degree of dependence of a node on a cluster. It shows that a node with higher dependence and responsiveness night often intend to support reliable transmission without undergoing high traversal and drop-probability. Furthermore, this research work and resulting outcomes have revealed that unlike multi-hop transmission based approaches the use of a single mobile sink can reduce traversal period, energy exhaustion due to retransmission (at multiple hops) and data drop probability. It can play vital role in assuring QoS delivery and energy efficient communication over WSNs. The use of CMIMO for transmission too have played significant role in assuring efficient communication. Thus, the proposed routing protocol, Q-E2RPC as cumulative solution has enabled an optimal routing protocol for QoS oriented and energy efficient communication over WSN.

6. Conclusion

In this paper a robust and efficient mobility assisted WSN routing protocol was developed. To achieve an energy efficient and QoS centric routing model, in this research work the emphasis was made on enhancing the key components such as network partitioning, enhanced clustering, soft-computing based cluster head selection, and CMIMO based transmission. The overall results obtained in terms of packet delivery ratio, energy consumption, delay and efficiency exhibit that Q-E2RPC outperforms traditional approaches applying CMIMO and single parameter based CH selection. In future, some other decision algorithms such as Neural Network or Evolutionary computing based approaches can be explored to assist clustering and CH selection.

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