ENERGY-EFFICIENT MOBILE SINK ROUTING SCHEME FOR CLUSTERED CORONA-BASED WIRELESS SENSOR NETWORK

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To my beloved husband who has always inspired and
encouraged me to move ahead in my life

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ABSTRACT

Wireless Sensor Networks (WSNs) are generally composed of several tiny, inexpensive and self-configured sensor nodes, which are able to communicate with each other via wireless communication devices. The main duty of the nodes is to sense data and transmit to a sink via multi- or single-hop data transmission manners. Since the sensor nodes generally are limited in power resources, they deplete their energy rapidly. In addition, sensor nodes are usually distributed in places, where may be too harsh to be accessible for human. Consequently, exchanging or recharging the power supplies of the sensor nodes is difficult. Therefore, energy efficiency is the most critical issue in design of WSN, which affects the lifetime and performance of the network. Several cluster-based schemes are proposed to enhance the energy efficiency; however, most of them generate sub-optimal clusters without considering both coverage and energy issues simultaneously. Furthermore, several mobility-based schemes are proposed in order to achieve balanced energy consumption through optimizing the sojourn time and sojourn location of Mobile Sinks (MS). Nevertheless, most of them adjust the sojourn time of MS under predictable mobility pattern. Moreover, in most of existing mobility based schemes, time limitation is not considered for optimizing the sojourn location of MS. The aim behind this research is to develop an Energy-efficient Mobile Sink Routing (EMSR) Scheme, which improves the energy efficiency. The EMSR is the incorporation of three schemes: Energy-efficient based Unequal-sized Clustering (EUC) mechanism aims to construct the optimal sized clusters, which ensures the energy conservation and coverage preservation. Collaborative Mobile Sink-based Inter-Cluster Routing (CMSICR) mechanism aims to optimize the sojourn time of MS to balance the energy consumption among Cluster Heads (CH). An Energy-efficient Intra-cluster Movement of Mobile Sink (EIM2S) mechanism, which identifies the optimal sojourn locations of the MS within clusters in order to balance the energy consumption among Member Nodes (MN). The EMSR partitions the network field into optimal clusters and employs MSs in order to balance the energy consumption among CHs and MNs. Simulation results show that EMSR achieved improved performance in terms of network lifetime by 51%, total energy consumption by 28% wasted energy by 36% compared to existing schemes. In conclusion, the proposed routing scheme proves to be a viable solution for multi hop cluster based WSN.

ABSTRAK

Rangkaian Sensor Tanpa Wayar (WSN) umumnya terdiri daripada beberapa nod sensor kecil, murah dan dikonfigurasi sendiri, yang dapat berkomunikasi antara satu sama lain melalui peranti komunikasi tanpa wayar. Tugas utama nod sensor ini adalah untuk mengesan data dan menghantar ke tumpuan melalui hop tunggal atau pelbagai. Walau bagaimanapun, nod pengesan ini kebiasaannya adalah terhad dari segi sumber kuasa, tenaga mereka akan berkurang dengan cepat. Di samping itu, nod pengesan biasanya terletak di pelbagai tempat, di mana ianya agak sukar diakses oleh manusia menyebabkan agak sukar untuk menukar nod yang baru atau mengecas bekalan kuasa untuk nod tersebut. Oleh itu, kecekapan tenaga adalah isu yang paling penting dalam reka bentuk WSN, di mana ianya mempengaruhi jangka hayat dan prestasi rangkaian. Beberapa skim berasaskan kluster telah dicadangkan untuk meningkatkan lagi kecekapan tenaga, walau bagaimanapun, kebanyakan antara skim ini menghasilkan kluster sub optimal tanpa mempertimbangkan isu liputan dan tenaga pada masa yang sama. Di samping itu, beberapa skim berasaskan mobiliti dicadangkan untuk mencapai penggunaan tenaga yang seimbang melalui mengoptimumkan jeda masa dan jeda lokasi takungan mudah alih (MS). Walau bagaimanapun, kebanyakan daripada mereka hanya menyesuaikan jeda masa MS di bawah pola mobiliti yang boleh diramal. Tambahan pula, di kalangan skim mobiliti yang sedia ada, kekangan masa tidak dipertimbangkan untuk mengoptimumkan jeda lokasi MS. Objektif kajian ini adalah untuk membangunkan Skim Penghalaan Takungan Mudah Alih Cekap Tenaga (EMSR) di mana ianya akan mempertingkatkan lagi kecekapan tenaga. EMSR merupakan penggabungan tiga skim: kecekapan tenaga berdasarkan mekanisma Saiz Tidak Selaras (EUC) bertujuan untuk membina kluster saiz yang optimal untuk memastikan pemuliharaan tenaga dan pemeliharaan kawasan liputan. Mekanisma Kerjasama Takungan Mudah Alih berdasarkan Penghalaan Antara Kluster (CMSICR) bertujuan untuk mengoptimumkan jeda masa MS bagi mengimbangi pengunaan tenaga di kalangan Ketua Kluster (CH). Mekanisma Kecekapan Tenaga Pergerakan Antara Kluster Takungan Mudah Alih akan mengenalpasti jeda lokasi MS kluster yang optimum bagi mengimbangi penggunaan tenaga dikalangan ahli nod (MN). EMSR membahagikan lapangan rangkaian kepada kluster optimum dan MS akan digunakan bagi mengimbangi penggunaan tenaga di antara CH dan MN. Keputusan simulasi menunjukkan EMSR mencapai prestasi yang lebih baik dari segi jangka hayat rangkaian sebanyak 51%, jumlah penggunaan tenaga sebanyak 28%, tenaga terbuang sebanyak 36% berbanding skim yang terdahulu. Kesimpulannya, skim penghalaan yang dicadangkan ini telah terbukti sebagai penyelesaian yang praktikal untuk kluster hop pelbagai berdasarkan WSN.

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ADC	-	Analogue to Digital Converter
ACT	-	Arranging Cluster sizes and Transmission ranges
BS	-	Base Station
CAR	-	Cluster-Ring Approach
CBWSN	-	Corona Based Wireless Sensor Network
CCWSN	-	Clustered Corona Based Wireless Sensor Network
CH	-	Cluster Head
DBS	-	Distance-based Segmentation
DECBAC	-	Difference between the Energy Consumption Before and After Clustering
DSBCA	-	Distributed Self- organization load Balanced Clustering Algorithm
DT-MSM	-	Delay Tolerant Mobile Sink Model
D-UCR		Dynamic Unequal Clustered Routing
EBCAG	-	Energy-Balancing unequal Clustering Approach for Gradient-based
EBDG	-	An Energy-Balanced Data Gathering
EDARA	-	Energy efficient Distance-Aware Routing Algorithm
EECS	-	Energy Efficient Clustering Scheme
EEUGCR	-	Energy Efficient Uneven Grid Clustering Routing
EMCA	-	Energy efficient Multi-sink Clustering Algorithm
HEED	-	A Hybrid, Energy-Efficient, Distributed Clustering
HUMS	-	Half-quadrant-based Moving Strategy
GMRE	-	Greedy Maximum Residual Energy
LBDC	-	Load Balanced Data Collection

LEACH	-	Low Energy Adaptive Clustering Hierarchy
LP	-	Linear Programming
MAC	-	Media Access Control
MEMS		Micro-Electro-Mechanical Systems
MILP	-	Mixed Integer Linear Programming
MN	-	Member Node
MS	-	Mobile Sink
NP	-	Non-deterministic Polynomial-time
OCCN	-	Optimal Clustering in Circular Networks
OLMS	-	Optimal Location for Mobile Sink
RP	-	Rendezvous Points
SM-NLI	-	Sink Mobility for Network Lifetime Increase
TSP	-	Traveling Salesman Problem
UCS	-	Unequal Clustering Size
WSN	-	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, Wireless Sensor Network (WSN) is comprehensively defined as the set of tiny and inexpensive sensor nodes scattered in an unattended area. Sensor nodes are Micro-Electro-Mechanical Systems (MEMS) that produce a measurable response to a change in some physical condition like temperature and pressure. These devices monitor and record the physical conditions of the environment and report the collected data to a central location called Base Station (BS) (Nack, 2010). The sensor nodes are able to construct a network structure without having any fixed infrastructure. However, due to technology limitation, sensor nodes usually are restricted in energy, memory, bandwidth and transmission power; such types of constraints have posed many issues in the design of WSNs.

Generally, coverage and energy consumption are two main metrics in determining the network quality (Sangwan and Singh, 2015). One of the design challenges of WSN is to optimize the distribution of these nodes in order to meet the coverage preservation. The coverage of the monitored area can be guaranteed through the careful planning of node densities, which can be established at the setup time. In many applications, the nodes are deployed randomly, whereas full coverage can be ensured by applying a little control in nodes densities, which results in uniform node distribution (Younis & Akkaya, 2008). However, energy constraint is still considered as one of the main design challenges for WSNs.

A sensor node expends energy for sensing, data processing and communicating. More energy is consumed for data communication than any other process. Due to limited power supplies, the sensor nodes exhaust their energy eventually. Accordingly, data transmission mechanisms between nodes and BS need to be designed based on energy efficiency, in order to keep the sensor nodes operational as long as possible thereby improving network lifetime (Asharioun *et al.*, 2015; Nikolov *et al*. 2017).

The manner of data dissemination from a sensor node to the BS is known as routing protocol for WSN, which takes place in the network layer of the protocol stack. Based on the network topology, there are two types of routing protocols in WSNs, namely: flat routing protocols and hierarchical routing protocols (Manap *et al.*, 2013). In a flat routing protocol, all nodes perform the same tasks and have the same functionalities in the network. However, in hierarchical topology protocol, nodes perform different tasks in WSNs and the network area is partitioned into multiple groups. Each group contains one head node and many ordinary nodes. In this kind of routing protocols, ordinary nodes deliver their sensory data to their respective head nodes, while a head node is responsible for collecting the data from ordinary nodes and then reporting to a BS. Hierarchical-based routing is a feasible solution for reducing energy consumption in WSNs due to reduction of redundant data transmission, which results in enhanced energy efficiency and network lifetime (Hong, *et al.*, 2009; Xu *et al.*, 2015; J. Yu *et al.*, 2011).

1.2 Problem Background

Sensor nodes are distributed in ad-hoc manner to monitor the physical area and gather information. Since the area wherein the network is implemented may be too harsh to be accessible for human, recharging or replacing the nodes is difficult (Asharioun *et al.*, 2015). In addition, due to limited energy supplies, sensor nodes deplete their energy quickly. Consequently, energy limitation is known as one of the most critical issue in design of the networks, therefore this resource should be utilized wisely. In the last years, several hierarchical-based protocols are proposed in order to prolong network lifetime and enhance the energy conservation. However, many critical issues still need to be considered while designing WSN protocols, such as energy efficiency, coverage preservation and balanced energy consumption.

Cluster-based routing protocols have become popular in recent years to improve the network performance and energy efficiency (Hong *et al*., 2009; Xu *et al*., 2015; J. Yu *et al*., 2011). In cluster-based WSNs, the nodes are classified into virtual groups as clusters. Each cluster comprises of one Cluster Head (CH) and several Member Nodes (MN), which sense the information from environment and send to their respective CHs. Then, CHs transfer the data packets towards BS after some data processing operations. Transferring the data packets from MNs to CHs or from CHs to BS can be performed either by single- or multi-hop transmission manners. A CH takes responsibility for gathering the data packets from MNs and forwarding to BS, which aims to improve network performance and energy efficiency through reducing the energy consumption of nodes. Most of previous cluster-based schemes emphasize on decreasing the energy consumption or load balancing among nodes in order to enhance network lifetime (Heinzelman *et al*., 2000; Lindsey & Raghavendra, 2002; Mahajan *et al*., 2014).

In cluster-based mechanisms, the size of clusters is one the design challenges of cluster based protocols. Several cluster-based schemes have been proposed to optimize the size of clusters in order to enhance energy efficiency (Arghavani *et al*., 2017; Mehmood *et al*., 2015; Moon & Han, 2015; Venkateswarlu *et al*., 2016). However, most of them construct sub-optimal clusters. Furthermore, CH performs a vital role for gathering the data packets from member nodes and transmitting toward BS. When a CH depletes its power supply completely, then it is no longer operational and network lifetime may be finished (Dahnil *et al*., 2012; Ruan *et al*., 2013). In fact, in cluster based WSNs, the lifetime of the network depends on the lifetime of CHs. The unbalanced load distribution among CHs leads to appear energy hole problem, which is one of the main causes of premature CHs death. In addition, according to the most of the existing clustering mechanisms, MNs inside the cluster regions transfer sensory data directly towards their respective CHs. Consequently, the nodes located farther from CHs require more energy for transmitting their data packets and exhaust their energy sooner than other nodes, which results in coverage problem in long run (Latif *et al*., 2016). The sub-sequent sections explain the issues and limitations of cluster-based routing protocols in details.

1.2.1 Non-optimized Cluster Size

In cluster based WSNs, the size of clusters has a key role in the network power consumption. If this parameter is not optimized, the total energy consumption of the network increase exponentially, either when the cluster size is smaller than the optimal value or when the cluster size is larger than the optimal size (Heinzelman *et al*., 2000). Furthermore, generating the small sized clusters leads to coverage hole problem (Latif *et al*., 2016; Moon & Han, 2015), as well as this property is opposite of being scalability of the network (Moon & Han, 2015). On the other hand, if this parameter is not adjusted properly, decreasing the energy consumption of nodes, which is the key objective of applying clustering, cannot be pursued, thus the clustering process will act contrary in this regard. Consequently, in order to guarantee the reduction of energy consumption after clustering, the energy consumption of nodes before clustering should be considered.

Dynamic sized clustering is generally considered as one of the energy conservation techniques, which is proposed for the first time in Energy Efficient Clustering Scheme (EECS) (Ye *et al*., 2005). EECS enhances Low Energy Adaptive Clustering Hierarchy (LEACH) scheme (Heinzelman *et al*., 2000) through employing dynamic cluster formation technique, which leads to enhance energy conservation. However, in such scheme, the size of clusters change frequently, which leads to extra network overheads. This drawback has been solved in Unequal Clustering Size (UCS) (Soro & Heinzelman, 2005) as the first unequal clustering scheme. The aim behind such schemes (Bagci & Yazici, 2013; Ever *et al*., 2012; Y. Liao *et al*., 2013; Selvi & Manoharan, 2015) is to address the energy hole problem, which appears in the clusters nearby the BS as these clusters need to handle the extra traffic load coming from the faraway clusters. In UCS, the sensing field is assumed to be circular and is divided into two concentric circles, called layers. It is assumed that all clusters in each layer have the same size and shape, but the sizes and shapes of clusters are dissimilar in two different layers, which leads to improve the energy efficiency. However, UCS is not applicable for large size networks since two-hop inter-cluster routing is employed.

Moreover, H. Zhang & Shen, (2009) proposed an Energy-Balanced Data Gathering protocol (EBDG) to enhance the balanced energy consumption of CHs belonging to different layers of the network. To achieve this goal, the network is divided into layers and layers into equal size sub-layers and finally sub-layers are divided into zones. The main objective of EBDG is to determine the optimal number of clusters, which is modelled as an optimization problem. Although, EBDG can balance the workload among different zones, however, this scheme is proper for small size networks since single hop is applied for inter-cluster communication. In addition, constructing the equal sized clusters throughout the network leads to high energy consumption for inter-cluster communication (Shu & Krunz, 2010). Likewise, a Coverage-Time Optimization based scheme is proposed by Shu & Krunz, (2010), which aims to determine the optimal cluster size in different layers of the network. A key requirement of such scheme is the number of clusters, which must to be given. However, constructing the optimal clusters with respect to the given number of clusters is non-trivial (Moon & Han, 2015). Moreover, to address the limitations of previous schemes, an Arranging Cluster sizes and Transmission ranges strategy (ACT) (Lai *et al*., 2012) have been introduced in order to mitigate the energy hole problem and prolong the network lifetime. In ACT, the topology of the network consists of multiple layers and the size of clusters belonging to each layer is determined according to the distance from BS. Although, this property can solve energy hole problem, however, ACT constructs the large size clusters in outermost layer of the network, which leads to increase the intra-cluster energy consumption of outermost clusters and excessive traffic load of inner clusters.

Likewise, Energy-Balancing unequal Clustering Approach for Gradient-based scheme (EBCAG) is introduced by T. Liu *et al*., (2012). The aim behind EBCAG is to determine the optimal cluster size in different layers of the network by calculating the gradient values of the CHs. The gradient value of a CH is computed based on the received data packets from the nodes. This scheme balances the energy consumption of CHs, as well as it overcomes the drawbacks of previous cluster size optimization based schemes. However, in EBCAG, the size of clusters is small and this property is opposite of being scalability of the network. This weak point has been eliminated in Distance-based Segmentation scheme (DBS) (Amini *et al*., 2012) through providing a mathematical framework to obtain the optimal cluster size in different layers of the network. DBS divides the network into equal rings or coronas and applies different clustering rules to each ring, which results in enhanced load balancing and energy conservation. Furthermore, a sub-optimal clustering algorithm named Optimal Clustering in Circular Networks scheme (OCCN) (Arghavani *et al*., 2017; Moon *et al*., 2017) is proposed, which aims to reduce the energy consumption and increase the lifetime of the network. In OCCN, the energy consumption is optimized by partitioning the network into nearly equal size clusters in a distributed manner. However, in DBS and OCCN schemes, the authors attempted to distribute the MNs into equal sized clusters, whereas it is perceived that equal sized clustering results in imbalance energy consumption during inter-cluster communications, which results in early partitioning of the network (Sabor *et al*., 2017).

Moreover, a Cluster-Ring Approach (CAR) (Moon *et al*., 2017) is proposed in order to enhance energy efficiency. The major idea behind the proposed scheme is to balance the energy consumption among different layers of the network by constructing the virtual cluster rings. A cluster ring is a chain of clusters, which have equal distance from the BS and conduct energy efficiency optimization at the cluster-ring level. This division results in enhancing scalability in the network. However, in CAR, only inter-cluster energy consumption is involved to determine the optimal cluster size and the energy consumption of MNs has been ignored, which leads to increase the intra-cluster overheads. Furthermore, in the uniform node distribution, the inner CHs can preserve some energy for the inter-cluster traffic, if clusters belonging to the inner layers have a smaller size in compared with outer layers. Nevertheless, this principle is not fulfilled in this approach. In addition, several routing protocols (Lakshminarayanan & Krishanan, 2014; X. Liu, 2016; J. Wang *et* *al*., 2017; J. Wang *et al*., 2017) applied clustering technique on a sink centric traffic pattern topology in order to achieve sub-balanced energy consumption of nodes. In such schemes, the network area is divided into rings or coronas, then the rings are divided into equal sectors with a constant angle. Afterwards, they employed different techniques to balance the energy consumption of CHs located at different rings. However, the optimal angle of sectors has not been discussed in existing works. Since the size of clusters in such schemes depends the angle of sectors, determining the optimal value for angle is imperative.

Based on aforementioned discussion, it is observed that most of the existing mechanisms construct the sub-optimal clusters without taking into account both energy and coverage issues simultaneously, which leads to coverage holes and compromised network lifetime. Generating the small clusters without considering the density of nodes, increase the probability of constructing empty clusters in the network, which results in coverage and connectivity problems. On the other hand, constructing the large size clusters leads to increase the intra-cluster overheads. Besides, reducing the energy consumption is one the critical goal of clustering technique; however, it cannot be pursued without comparing the energy consumption before and after clustering in optimizing the cluster size. Therefore, it is required to present a mechanism, which considers both energy-efficiency and coverage-guarantee in order to improve energy conservation and coverage preservation in the network.

1.2.2 Unbalanced Energy Consumption of CHs

In multi hop clustering WSNs, the CHs located around BS consume more energy since they are not only responsible for gathering and transmitting the sensory data from their own MNs, but also for relaying the data packets from outer CHs to inner CHs. Accordingly, the CHs located nearby the sink deplete their energy quicker than outer ones. This unbalanced energy consumption of CHs leads to appear energy holes around BS, which results in premature network death and wasting the 90% of the energy of the network (Asharioun *et al*., 2015). In the past few years, several sensor network applications employed Mobile Sinks (MS) in order to transfer the burden of energy consumption from the sensors to sinks, which are typically considered to have an unlimited energy supplies and larger computational power (Guo, 2012). In such schemes, MS traverses the monitoring region and stops at several sojourn positions for a limited sojourn time to collect the data packets from nodes. In some existing MS based schemes, sojourn time of MS is optimized at different sojourn locations in order to overcome energy holes and enhance the network lifetime (Akbar *et al*., 2017; Lee *et al.* 2014; Saad & Tourancheau, 2009).

The sojourn time of MS is optimized for the first time by Z. M. Wang *et al.* (2005) in order to enhance the network lifetime. A linear programming formulation is presented for the joint problems of determining the movement of the MS and its sojourn time at different sojourn locations, which results in prolonged network lifetime. However, due to utilizing only mobile type sink in the network, sensor nodes have to buffer their sensory data and send to MS whenever it arrives to their locations, which leads to buffer overflow and increased data loss in the network. Furthermore, energy hole problem has not been addressed in this scheme. likewise, an extension of Wang's model proposed by Basagni, *et al*. (2008) to mitigate the energy holes through determining an optimal tour for travelling of MS. In such scheme, MS stays at the energy hole prone locations in order to solve energy hole problem. In addition, the sojourn time of MS in each sojourn location is optimized to maximize the network lifetime. However, in such scheme, MS frequently needs to collect the required information for inspecting the locations where surrounded by the nodes with higher remaining energy as its next sojourn location, which imposes extra overheads.

To overcome the aforementioned limitations of existing schemes, Saad & Tourancheau, (2009) proposed an Integer Linear Programming (ILP) based scheme. The main objective of this scheme is to mitigate the energy holes by adjusting the sojourn locations and sojourn time of mobile sinks. In this scheme, MSs should stay at each site for a limited sojourn time, which is determined with the objective of maximizing the network lifetime. Moreover, the minimum sojourn time of MS at each sojourn location is considered to ensure that other sensor nodes will be served before ending the network lifetime. In addition, mobile sink stays most of times at the nodes, which have the minimum number of hops to other sensor nodes. Although this strategy can enhance the energy conservation, however, it has few limitations; firstly, since this scheme is designed especially for grid distribution of nodes, this scheme cannot be appropriate choice for the network with irregular node distribution. Secondly, the energy hole-prone locations are inspected during the network operation thereby incur extra overhead. Third, since they consider the minimum sojourn time at each location, the balanced energy consumption cannot be ensured.

An improved approach was proposed by Liang & Luo, (2011), which aims to enhance the network lifetime by determining the optimal trajectory and sojourn time of MSs at each sojourn location. Unlike the scheme carried out by Saad and Tourancheau (2009), this approach works for large-scale sensor networks with irregular node distribution. Furthermore, the sojourn time of MS is optimized at each sojourn location to maximize the network lifetime by an ILP. Although, a strong heuristic technique is proposed to solve the aforementioned problem, however, the high time complexity of the proposed scheme makes it infeasible to be used dynamically in a sensor network. Moreover, in such schemes (Keskın, Altınel, Aras, & Ersoy, 2011; Lee *et al*., 2014; Shi, Wei, & Zhu, 2016), the sojourn locations of MS are inspected during the movement of MSs, which leads to increase the network overhead. To address the aforementioned problems, Akbar *et al*., (2017) proposed a new scheme for data gathering in WSNs, which the trajectory of MS is predefined. In this work, the network field is divided into small regions and the sojourn time of MS is equal at all sojourn locations. In addition, sleep and awake technique has been applied for gathering the data packets from sensor nodes. Consequently, the nodes which are only located within the sensing range of MS can send their data packets to MS and other ones go to sleep mode to save their energy. However, increasing the sojourn time of MS in each sub-region leads to high latency problem. The latency caused by periodic sleeping is called sleep delay problem that decrease the network performance (Ye, Heidemann, & Estrin, 2004).

Based on the aforementioned discussion, it is observed that most of existing schemes calculate the sojourn time of MS under an unpredictable mobility pattern. In such schemes, the sojourn locations of MS are identified during the network operation, which incur extra overhead. In addition, it is examined that predefined mobility pattern can reduce the total energy consumption of the network (Somasundara, Kansal, Jea, Estrin, & Srivastava, 2006). Furthermore, for very high sojourn time of MS in each location, it is not even possible for the MS to sojourn at all sojourn locations and the network lifetime is reached before the MS can serve all sensor nodes. Therefore, defining a proper threshold for sojourn time of MS at each location is needed, however, it is ignored in most of previous schemes. Accordingly, there is significantly need to present a mobile sink based inter-cluster routing mechanism to balance the energy consumption among CHs by optimizing the sojourn time of MS in each sojourn location under a predicable mobility pattern.

1.2.3 Unbalanced Energy Consumption of MNs

For intra-cluster routing, most of existing schemes adopt direct data transmission manner for transmitting the sensory data from MNs to their respective CHs. (Lakshminarayanan & Krishanan, 2014; Soro & Heinzelman, 2005; J. Wang, Yin, Zhang, Lee, & Sherratt, 2013). Since, the energy consumption of nodes depends on their transmission power, the nodes located farther from CH require more energy for transmitting their data packets. Therefore, by increasing the distance between nodes and CH, The energy consumption of MNs increase and the MN located at the farthest point from CH, depletes its energy supply earlier than other ones. Subsequently, the environment of the MN that depletes its energy cannot be monitored, which leads to appear coverage holes and degrade the coverage time of the network (Latif *et al*., 2016). The coverage time is the time until first MN runs out of battery, resulting in an incomplete coverage of the sensing region. Generally, employing MSs can enhance the balanced energy consumption of member nodes. Determining the optimal sojourn locations of MS is one of the major design issues in mobility-based schemes (Luo & Hubaux, 2010). The sojourn positions of MS are the set of locations, where MSs stop to serve the sensor nodes.

In the past years, several MS based schemes have been developed to optimize the sojourn locations of MS in order to balance the energy consumption of sensor nodes (Bi *et al*., 2007; Chatzigiannakis, Kinalis, & Nikoletseas, 2008). In such schemes, mobile sinks autonomously move throughout the network with different principles. Although, balanced energy consumption has been acheived, however, they are specially designed for small size networks and cannot be appropriate for large size sensor networks. To improve the earlier solutions, (Marta & Cardei, 2008) have proposed a scheme, which designed for large size networks. A Sink Mobility for Network Lifetime Increase (SM-NLI) problem is formulated, which the objective is to design a movement pattern in order to balance the energy consumption among sensors. In such scheme, mobile sink searches for area of sensors with high residual energy not only the node with highest remaining energy. However, mobile sink must be frequently informed about the residual energy of nodes, which leads to excessive communication overhead.

Khodashahi *et al*., (2010) proposed a mobility based clustering routing protocol named Optimal Location for Mobile Sink (OLMS), which aims to minimize the energy cost for data communication. In such scheme, after CH election phase, each sensor node creates a table for determining the best location for MS by considering the energy consumption of all CH nodes. Subsequently, the location with minimum data communication for all CHs is elected as the sojourn location of MS. OLMS technique improves the network lifetime in comparison with the schemes that sink moves randomly or moves to the node with highest residual energy. However, it is not suitable for dense and large size networks because retaining a table at each sensor node causes storage overhead. To overcome storage overhead problem, several scheme have been designed (J. Wang, Li, Xia, Kim, & Kim, 2014; J. Wang, Zuo, Zhang, Xia, & Kim, 2013) so that all information is summarized into only one table, which stores the previous sojourn locations of mobile sinks in order to determine the optimal sojourn position. However, these schemes similar to technique proposed by Khodashahi *et al*., (2010), imposes extra overheads to maintain the previous positions of sink.

Moreover, visiting the every sensor nodes by sink increases the travel path and results in buffer overflow due to data collection delays. To address this problem, several rendezvous-based strategies have been proposed (Almi'ani, Viglas, & Libman, 2010; Gao, Zhang, & Das, 2011; W.-H. Liao, Yen, & Kuai, 2015; Salarian, Chin, & Naghdy, 2014), which aim to balance energy consumption among nodes. In such schemes, MS can only visit the subset of sensors instead of all sensor nodes in the network. Although these schemes can improve the energy efficiency to an acceptable levels, however, time complexity of rendezvous-based strategies is high since calculating the weight of all sensor nodes is required in every rounds. To improve the existing rendezvous-based strategies, Moh'd Alia, (2017) proposed an energy efficient network model, which dynamically relocates a MS within a cluster-based network. To solve the limitations of previous rendezvous-based strategies, in this scheme, the weights of only some specific locations are calculated instead of all sensor nodes. The aim behind this scheme is to balance the energy consumption among CHs. To achieve this goal, the optimal sojourn location of the MS is determined between the CHs and the MS in such a way that the communication range of all CHs is balanced. However, in this approach, the number of sojourn locations is not specified, which leads to extra network overheads.

Furthermore, Kaswan et al., (2017) proposed an algorithm to determine the efficient trajectory for MS based on rendezvous points. They attempt to minimize the subset of rendezvous points in such a way that all sensor nodes are covered by rendezvous points in a single hop communication. Based on the literature review, most of the existing schemes do not optimize the sojourn locations of mobile sink while keeping in view the time limitation, which leads to decrease the network performance and coverage time. Moreover, in most of previous mobility-based clustering algorithms, MS stays at only one location within a cluster for a limited time. However, the movement of MS along multiple sojourn locations within the clusters can solve the unbalanced energy consumption of MNs. Thus, an energy-efficient intra-cluster routing mechanism should be discovered to balance the energy consumption among MNs during a limited sojourn time by optimizing the sojourn locations of MS in each cluster.

1.3 Problem Statement

In the last years, cluster based approaches have been widely used in WSNs, because of its advantages, such as less energy consumption, less load and longer network lifetime. However, most of the existing cluster based routing protocols, construct sub-optimal clusters without considering both energy and coverage issues simultaneously. In addition, decreasing the energy consumption of nodes, which is one of the objectives of applying clustering, has not been considered in most of previous studies. Moreover, several cluster based schemes utilize mobile sinks in order to solve the energy hole problem by optimizing the sojourn time of mobile sinks in different sojourn locations. Nevertheless, most of them have been designed especially for unpredictable mobility pattern networks. Whereas, it is observed that predicable mobility pattern can enhance the energy conservation in the sensor networks (Somasundara *et al*., 2006). Likewise, unbalanced energy consumption of MNs is another problem, which leads to coverage hole problem in long run, however, much less attention has been devoted to solve this problem. Furthermore, several mobile sink based schemes have been presented in order to balance the energy consumption of nodes by optimizing the sojourn location of sink. Nevertheless, time limitation for balancing the energy consumption of nodes is not taken into consideration in most of the previous schemes, which leads to decrease the network performance. This research addresses the problem of limited energy supplies of sensor nodes, which reduce the network lifetime.

1.4 Research Questions

Based on the discussion in the section 1.2 the questions of research are as follows:

i. What is the optimal size clusters in order to achieve both energy efficiency and coverage issues?

a. How to generate the optimal sized clusters in order to ensure the energy consumption reduction after applying clustering?

b. How to construct the optimal sized clusters in order to preserve the coverage in the network?

ii. How to balance the lifetime of CHs belonging to different layers of the network to enhance the network lifetime?

a. What is the optimal sojourn time of mobile sink in each cluster in order to balance the lifetime of CHs located at different layers of the network?

b. How to determine the sojourn time of mobile sink under a predictable mobility pattern?

c. What is the optimal threshold for sojourn time of mobile sink in each cluster in order to increase the number of clusters, which can be served by mobile sink?

iii. How to balance the energy consumption of MNs within a cluster to enhance the coverage time of the network?

a. How to optimize the sojourn location of mobile sink in each cluster in order to balance the energy consumption of MNs?

b. How to optimize the sojourn location of mobile sink in each cluster with respect to allocated sojourn time to cluster?

1.5 Research Aim

This research aims to develop an Energy-efficient Mobile-sink Routing mechanisms for clustered corona-based WSNs to improve the energy efficiency, prolong the network lifetime and enhance the coverage time of the network.

1.6 Research Objectives

The following objectives of study are to be achieved during the research work. These objectives are in the prospect of the research questions mentioned in section 1.4.

i. To develop an optimal clustering mechanism that enhances energy efficiency while guaranteeing the coverage issue thereby enhancing the network performance and energy conservation.
ii. To develop a mobile sink based inter-cluster routing mechanism, which optimizes the sojourn time of mobile sink in each cluster under predefined mobility pattern thereby enhancing the network lifetime.
iii. To develop a mobile sink based intra-cluster routing mechanism that inspects the optimal sojourn locations of sink within clusters thereby balancing the energy consumption of member nodes within a limited time.

1.7 Research Contributions

The main contributions of this research work are summarized as follows:

i. The Energy-efficient based Unequal-sized Clustering (EUC) mechanism that optimizes the size of clusters in different layers of the network thereby enhancing the energy conservation and coverage preservation.
ii. The Collaborative Mobile Sink-based Inter-Cluster Routing (CMSICR) mechanism, which formulates the optimal sojourn time of sink in each cluster to balance the lifetime of clusters belonging to different layers thereby enhancing the energy conservation and network lifetime.
iii. The Energy-efficient Intra-cluster Movement of Mobile Sink (EIM2S) mechanism that determines the optimal sojourn positions of sink within clusters by considering allocated sojourn time to the clusters thereby balancing

the energy consumption among member nodes and enhancing network performance.

1.8 Research Scope

The scope of the research are:

i. In this research, both static and mobile sinks are location aware, since they are equipped with GPS.
ii. This research considered flat network and outdoor field, where there are no obstacles between sensor nodes.
iii. Event based sensing is not considered so that sensor nodes sense data on a periodic base.
iv. The issues related to Internet Protocol (IP) addressing and IP mobility management are considered out of this study scope.
v. The communication security-related issues are out of this study scope.

1.9 Significance of Research

This research focuses on improving mobile sink based energy-efficiency and coverage-guarantee inter- and intra-cluster routing scheme, which is able to generate optimal sized clusters. This proposed scheme is compatible for plenty of applications that need energy efficiency such as habitat monitoring, fire detection, water contamination, area monitoring and object tracking. In this kind of applications, since the network place is harsh to be accessible by human, the batteries of sensor nodes cannot be replaced or recharged after deployment. Furthermore, sensor nodes are usually equipped with limited energy supplies and deplete their power resources rapidly. Therefore, an energy efficient routing protocol is needed to keep the sensor nodes operational for a longer time thereby increasing the network lifetime. In addition, in a wide range of civilian and military applications, including security surveillance (e.g., to alert of terrorist threats), environmental monitoring, hazard and disaster monitoring, sensing coverage is one of the most fundamental issues to ensure effective environmental sensing (Li *et al*., 2009). Accordingly, a reliable routing scheme is required to preserve the coverage issue in the network. The proposed mobile sink based energy efficient inter- and intra-cluster routing scheme offers a reliable solution to network communication, which covers energy-efficiency and coverage-guarantee issues.

1.10 Thesis Organization

This thesis comprises of seven chapters. The rest of the chapters are organized as follows:

Chapter 2 presents an extensive literature review of research area and problem backgrounds. It highlights the weak points and positive points of most of the proposed cluster size optimization based schemes, sojourn time of MS optimization based strategies, and sojourn locations of MS optimization based schemes.

Chapter 3 describes the research methodology and experiments environment used to achieve and verify this research objectives. In addition, it depicts the design, implementation and verification process of the proposed schemes of EMSR.

Chapter 4 describes the design and development of Energy-efficient based Unequal-sized Clustering (EUC) mechanism to improve cluster formation. In addition, the efficacy of clustering algorithm is evaluated and analysed against other relevant clustering algorithms.

Chapter 5 presents the design and development of Collaborative Mobile Sink-based Inter-Cluster Routing (CMSICR) mechanism. Furthermore, simulation experiments are carried out in order to measure the relative performance of CMSICR mechanism against other relevant mobile sink based routing algorithms.

Chapter 6 describes the design and development of Energy-efficient Intra-cluster Movement of Mobile Sink (EIM2S) mechanism in order to balance the energy consumption among member nodes and improve network performance. Moreover, the simulation based performance evaluation are performed in order to measure the relative performance of EIM2S mechanism against other relevant algorithms.

Chapter 7 concludes the contributions that are made in this research and suggests possible future directions.

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