[UCI]I804:24011-200000267371

2019 년 8 월

석사학위논문

Game-Theory-Based Clustering for Multisink Wireless Multimedia Sensor Networks

MD ARAFAT HABIB

2019년 8월

석사 학위 논문

Game-Theory-Based Clustering for Multisink Wireless Multimedia Sensor Networks

조선대학교 대학원

컴퓨터공학과

MD ARAFAT HABIB

August 2019

Master's Degree Thesis

Game-Theory-Based Clustering for Multisink Wireless Multimedia Sensor Networks

Graduate School of Chosun University

Department of Computer Engineering

Md Arafat Habib

Game-Theory-Based Clustering for Multisink Wireless Multimedia Sensor Networks

다중 싱크 무선 멀티미디어 센서 네트워크를 위한 게임 이론 기반 클러스터링

August, 2019

Graduate School of Chosun University

Department of Computer Engineering

Md Arafat Habib

Game-Theory-Based Clustering for Multisink Wireless Multimedia Sensor Networks

Advisor: Prof. Sangman Moh, Ph.D.

A thesis submitted in partial fulfillment of the requirements for a Master's degree

April 12, 2019

Graduate School of Chosun University

Department of Computer Engineering

Md Arafat Habib

하빕 엠디 아라팟의 석사학위논문을 인준함

위원장	조선대학교 교수	정일용	(인)
위　원	조선대학교 교수	신석규	(인)
위　원	조선대학교 교수	모상만	(인)

2019 년　5 월

조선 대학교 대학원

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

WMSN	Wieless Multinedia Sensor Network
QoS	Quality of Service
WSN	WirelessSensor Network
FoV	Field of view
RPAR	Real-time and Power Aware Routing
DARA	Distributed Aggregate Routing Algorithm
OCRP	Operator Calclulus-based Routing Protocol
EG	Evolutionary Game
CH	Cluster Head
CM	Cluster Member
EGR	Evolutionary Game-based Routing
QMOR	Quality-Aware Multi-sink Opportunistic Routing
LEACH	Low Energy Adaptive Clustering Hierarchy
ASAR	Ant-based Service-Aware Routing Algorithm
PPDD	Path-length-based proportional delay differenciation
AB	Alaei and Barcelo-Ordinas
SN	Sensor Node
ADV	Advertisement
ESS	Evolutionary Stable Strategy
IEEE	Institute of Electrical and Electronics Engineers
UAV	Unmanned Areial Vehicle
CCMR	Cross-layer based Clustered Multipath
EEQAR	Energy Efficient QoS Assurance Routing
MQSR	Multipath QoS-aware Routing
CAQR	Correlation Aware QoS Routing
PEMuR	Power Efficient Multimedia Routing
PRMD	Priority-based Routing for Multimedia Data Delivery

ADSR	Angle-based Differenciated Services Routing
AGEM	Adaptive Greedy Compass Energy-aware Multipath
REAR	Realtime Energy-Aware Routing
TPGF	Two Phase Greedy Forwarding
LANMAR	Landmark Adhoc Routing Protocol
GEAMS	Geographic Energy-aware Multipath Streaming

ABSTRACT

Game-Theory-Based Clustering for Multisink Wireless Multimedia Sensor Networks

Md Arafat Habib
Advisor: Prof. Sangman Moh, Ph.D.
Department of Computer Engineering
Graduate School of Chosun University

Wireless multimedia sensor networks (WMSNs) are being used for various application areas these days. In the deployment of WMSNs, an energy-efficient and robust routing protocol is crucial because the quality of service is very important for traffic-intensive multimedia data including videos. Also, data volume is very high in WMSN since the transceivers have to deal with bulky multimedia data. Like wireless sensor networks (WSNs), cluster-based routing protocols are widely used in WMSNs. In particular, a WMSN with multiple sinks allows cluster heads (CHs) to deliver the gathered data to the nearest sink, mitigating delivery overhead. Game theory is a popular and useful technique to design clustering protocols for WSNs. Use of game theory for WMSN paradigm is still not well explored. Among different types of game-theoretic-techniques, evolutionary games are highly suitable for CH selection and resolving energy imbalance in the network. In this study, we propose a novel evolutionary-game-based clustering (EGC) protocol for WMSNs with multiple sinks, where the evolutionary game theory is exploited in selecting CHs. In EGC, a data redundancy avoidance algorithm based on the overlapped field of views of the multimedia sensor nodes is also presented, which decreases the number of redundant transmissions and thus increases energy efficiency and network

performance. According the performance evaluation results, the proposed EGC significantly outperforms the state-of-art protocols in terms of energy efficiency, end-to-end delay, packet delivery ratio, and network lifetime.

한 글 요 약

다중 싱크 무선 멀티미디어 센서 네트워크를 위한 게임 이론 기반 클러스터링

하빕 엠디 아라팟
지도교수: 모상만
컴퓨터공학과
조선대학교 대학원

무선 멀티미디어 센서 네트워크(WMSN)는 요즘 다양한 응용 분야에 사용되고 있다. WMSN 에서는 비디오 등 트래픽 집약적인 멀티미디어 데이터의 서비스 품질이 매우 중요하기 때문에 에너지 효율적이고 강인한 라우팅 프로토콜이 요구된다. 또한, 멀티미디어 데이터를 다루어야 하기 때문에 WMSN 에서는 데이터 용량이 매우 크다. 특히, 다중 싱크를 갖춘 WMSN 은 클러스터 헤드(CH)가 수집된 데이터를 가장 가까운 싱크로 전달하여 전달 오버헤드를 완화할 수 있다. 게임 이론은 무선 센서 네트워크 라우팅 프로토콜을 설계에 매우 유용한 방법론이다. 하지만 WMSN 패러다임을 위한 게임 이론의 사용은 아직 심도있게 탐구되지 않고 있다. 여러 종류의 게임 이론 기술들 중에서 진화 게임은 CH 선택과 네트워크의 에너지 불균형 해소에 매우 적합하다. 본 연구에서는 복수의 싱크를 갖춘

WMSN 을 위한 새로운 진화 게임 기반 클러스터링(EGC) 프로토콜을 제안한다. 여기서 진화 게임 이론은 CH 를 선택하는데 이용된다. EGC 에서는 멀티미디어 센서 노드의 시야 중첩에 기초한 데이터 이중화 회피 알고리즘도 제시되어 중복 전송 횟수가 감소하여 에너지 효율과 네트워크 성능이 향상된다. 성능 평가 결과에 따르면, 제안한 EGR 은 에너지 효율, 종단간 지연시간, 패킷 전달률, 네트워크 수명 측면에서 종래의 프로토콜을 크게 능가한다.

I. INTRODUCTION

A wireless multimedia sensor network (WMSN) consists of wirelessly interconnected devices capable of retrieving multimedia contents such as video, audio, still images, and scalar data from environment [1-3]. The improvement and miniaturization of hardware have led to the development of sensor devices equipped with audio-visual multimedia modules [4]. In recent times, the availability of cheap hardware such as cameras and microphones has put a great impact on the development of WMSNs. According to [5], WMSN is a network of wirelessly interconnected sensor nodes that have multimedia devices and can retrieve video and audio streams along with the scalar sensor data. WMSNs can facilitate a wide range of applications in both civilian and military areas. Surveillance sensor networks, law-enforcement reports, traffic control systems, advanced health care delivery, automated assistance to elderly telemedicine, and industrial process control can be some examples of such applications. In these applications, multimedia sensor nodes can increase the level of information collected, enlarge the range of coverage, and enable multi-resolution views [5]. Multimedia sensor nodes can collect snapshot and streaming multimedia contents. Snapshots are captured due to any event-triggered observation over a short period of time [4]. On the contrary, streaming multimedia contents are captured and generated for a longer period. It is highly necessary for WMSNs to have strong foundation of hardware to ensure quality of service (QoS) requirements and fulfill application-specific demands.

WMSNs require high bandwidth in comparison to traditional wireless sensor networks (WSNs). For example, Crossbow [6], which is an IEEE 802.15.4 compliant WSN platform, has a data transmission rate of 250 kb/s which is very low for high-end multimedia sensors. For supporting high data rate, WMSNs are required to be energy-efficient, and thus more careful considerations should be given to save energy. Multimedia sensors produce high volume of data that require extensive processing. This consumes much energy and has a great effect in network lifetime. On the other hand, multimedia sensor nodes have a different concept of sensing region compared to traditional WSNs. They have field of view (FoV) and can capture images within a particular region. Such kind of operation is quite different from the sensing operation in traditional WSNs. FoV refers to the directional view of a multimedia sensor. The target object covered by a camera can be in a distant position. Images captured by the camera depend on the relative position and orientation of the camera towards the targeted object [7-9].

Over the past few years, many routing protocols have been proposed for WMSNs, which focus on energy efficiency, delay, and reliability. Real-time power aware routing (RPAR) [10] could dynamically adjust transmission power and routing decision according to network load and data packet size. Its unique forwarding and neighbor management mechanism could effectively save energy while meeting real-time constraints. Despite its advantages, RPAR fails to consider hole and congestion issues. The routing protocol in [11] takes a cross-layer design approach between network layer and MAC layer to distinguish the communication flows with different delay and reliability demands. It lacks a control for redundant data, resulting in the decreased energy efficiency and increased communication congestion. Distributed aggregate routing algorithm (DARA) [12] determines the multiple paths for multiple sinks while ensuring reliability. Operator calculus-based routing protocol (OCRP) [13] utilizes operator calculus methods on graphs to solve the multi-QoS constrained routing problem. In this protocol, a node chooses the set of eligible next hops based on the given constraints and the distance to the sink. However, it ignores the impact of estimation accuracy on delay and reliability. The use of multiple sinks can be beneficial for WMSNs. To be robust to sink failure, it is necessary to deploy multiple sinks in the network. That is, it has length bound paths to at least two sinks. If any multimedia sensor node fails to send data due to sink failure, it can send data to another sink node alternatively. Also, multiple sinks are helpful to implement advanced applications and programming abstractions for routing algorithms and to avoid network congestions. So far, two routing protocols have been proposed for WMSNs, which implement multiple sinks. In [14], multi-sink aware operations were integrated into an opportunistic routing framework with an objective to reduce energy consumption. Tong *et al*. [15] propose CodeMesh, a coding-aware cross-path anycast routing protocol to maximize the lifetime of time-driven multi-sink networks. CodeMesh combines proactive and reactive protocol features while taking advantages of the benefits from multiple sinks. Its route establishment does not rely on clock synchronization. However, it lacks a scheduling mechanism to improve real-time performance.

Recently, game theory has become a popular and useful tool in WSNs. It is because game theory can be widely used for modeling the interactions among entities with conflicting interests, which are competent to each other in a resource constrained scenario. Four types of games have been used in routing for WSNs, which are cooperative game, noncooperative game, evolutionary game, and reputation-based game [16]. In evolutionary game (EG), the behavior of a large number of agents that repeatedly engage in strategic interactions is studied. In EG, there are many behaviors involving the interaction of multiple organisms in a population. The success of any of the organisms is highly dependent on how its behavior interacts with others [16]. Therefore, the fitness of an organism should not be measured individually; instead, it is to be measured in the paradigm of the full population. Two of the biggest benefits of using EG to design clustering protocols for WMSN are that cluster heads (CHs) can be elected optimally using EG and it can exploit energy imbalance among the nodes in EG formulation. A lot of clustering protocols have been designed for traditional WSNs using game theory. For WMSNs, however, we have found only one routing protocol that is partially based on game theory. That is, a combination of game theory and ant colony algorithm is presented in [17] to solve the problem of QoS routing in WMSNs. Such combination is adopted to have a triumph over the drawback of the current ant-based routing protocols for WMSNs. Game theory in this routing algorithm is based on the assumption that the sensor nodes are rational and opts for selfish actions (maximizing pay-offs at a minimum cost). Unfortunately, the paper does not provide any performance evaluation of the proposed routing scheme. To the best of authors' knowledge, no routing protocol using EG for WMSNs has yet been reported in the literature.

In this thesis, an evolutionary-game-based clustering (EGC) protocol for WMSNs with multiple sinks is proposed, which is a cluster-based routing protocol with the intelligent mechanism of CH election. Clusters are formed based on the overlapped FoV of the nearby sensor nodes. For every cluster, a CH is elected using EG. A data redundancy avoidance mechanism is also proposed. The overlapped area of the FoV of an object shared by two nearby sensor nodes is calculated, and it is decided if the captured data is redundant. Such an approach decreases number of redundant transmissions and thus increases energy efficiency and network performance. The proposed EGC is compared with the three protocols of QoS aware multi-sink opportunistic routing (QMOR) [14], the routing protocol designed by Alaei and Barcelo-Ordinas [19] that we call AB routing in this paper, and low energy adaptive clustering hierarchy-centralized (LEACH-C) [20]. According to our performance evaluation results, the proposed EGC outperforms QMOR, AB routing, and LEACH-C in terms of energy efficiency, end-to-end delay, packet delivery ratio, and network lifetime. In particular, the proposed EGC shows 66.8%, 42.2%, and more than 200% less end-to-end delay compared to QMOR, AB routing, and LEACH-C, respectively.

The contribution of this work can be summarized as follows:

- The unique and intelligent way of CH election using EGT has made the proposed clustering protocol highly energy efficient by introducing rationality among the nodes in the clusters. Nodes with higher level of residual energy in the clusters tend to become CHs in each round successfully. Even though, EGT has been used in clustering protocols for WSN, this is the first attempt in the literature to use EGT for clustering in WMSN.
- The avoidance of data redundancy based on the calculation of the overlapped region by two nearly placed sensor nodes is introduced. Due to this technique, significant increase in the network lifetime is observed.
- The proposed EGC makes the delivery of sensed data faster and more reliable by effectively exploiting the multi-sink environment.
- The proposed EGC outperforms the conventional routing protocols in terms of energy efficiency, end-to-end delay, packet delivery ratio, and network lifetime.

A. Research Objective

Despite the promising applications of WMSN, there are still not many protocols that have been developed to handle energy, delay and reliability requirements for such kind of network. The design of routing protocols has a significant impact on energy efficiency, end-to-end delay, reliability, and QoS provision. Handling high data volume in an energy efficient manner, ensuring lesser end-to-end delay, higher packet delivery ratio, and increased network lifetime are key parameters to design a robust routing protocol for WMSN. Our goal is therefore, to present an energy efficient cluster-based routing protocol using game-theory that uses an intelligent game theortetic method for CH election with multiple sink nodes in order to increase network lifetime, packet delivery ratio, and decrease end-to-end delay.

B. Thesis Layout

The rest of the thesis is organized as follows: In chapter II, several existing routing protocols proposed for WMSNs are reviewed. The network model of the proposed clustering protocol is presented in chapter III. The analytical description of the proposed protocol is described in chapter IV. In chapter V, the performance of the proposed EGC is evaluated via computer simulation and compared with the state-of-art protocols. Finally, the conclusions of the thesis and future works are provided in chapter VI.

II. RELATED WORKS

In this section, we review the routing protocols designed for WMSNs. Several routing protocols have been proposed so far that exploits different kinds of methods to achieve data reliability, energy efficiency, etc. to facilitate WMSNs.

An image transmission framework for optimizing perceptual quality and energy expenditure in WMSNs was reported in [18]. The goal of the scheme is to ensure the perceptual quality at the end user through the use of an analytical distortion model. The model could predict the image distortion resulting from any error pattern. The outstanding point of the proposed scheme in [18] is the use of a content-aware packet prioritization along with an energy- and delay-aware routing protocol.

In [21], an ant-based service-aware routing algorithm (ASAR) for WMSN is proposed. The routing algorithm opts for appropriate paths for variant QoS requirements. The routing scheme is mainly based on data transfer between CHs and sink node where CHs transfer different classes of data. To fasten the convergence of the algorithm and optimize network resources, the proposed algorithm in [21] quantifies the phenomenon value on the sink node in order to reduce sending frequency and control messages.

A combination of game theory and ant colony algorithm is presented in [17] to solve the problem of QoS routing in WMSN. Such combination is adopted to have a triumph over the drawback of the current ant-based routing protocols for WMSNs which is referred as the long time required by forwarding ants to sort out the destination and overhead occurred due to the use of many backward ants that update the routing probability distribution. Game theory in this routing algorithm is used based on the assumption that the sensor nodes are rational and opts for selfish actions (maximizing pay-offs at a minimum cost). Unfortunately, the paper does not provide any performance analysis of the proposed routing scheme.

A QoS aware routing protocol is presented in [22] that supports high data rate for WMSNs and ensures the bandwidth, end-to-end delay requirements of real-time data. The proposed routing scheme in [22] uses multiple paths, channels and QoS packet scheduling techniques based on dynamic bandwidth adjustment and path-length-based proportional delay differentiation (PPDD) techniques to fulfill the bandwidth and delay requirements respectively. The requirements of bandwidth and delay are adjusted locally at each node. Nodes in [22] are homogeneous and are responsible for performing application specific tasks like video, audio or scalar data acquisition, etc. Protocol proposed in [22] improves average delay per real-time packet, average lifetime of a node, and throughput of non-real-time data.

A dynamic node collaboration scheme based on FoV for a target tracking application is presented in [23]. Unlike traditional sensing models, it is a nonlinear localization-oriented sensing model for WMSN. It is based on clustering and exploits Montecarlo techniques to estimate target locations cooperatively. The protocol was intended for mobile target tracking using camera sensors by considering perspective projection and observation noises.

As discussed earlier data volume is high in WMSN, data redundancy can lead to significant level of energy wastage and reduced network lifetime. There are so far two works that have worked upon routing to avoid data redundancy. QMOR is one of them. The focus of this work lies in selecting and prioritizing forwarder list to gain an energy-efficient delivery of multimedia data under specific QoS requirements. First, the protocol introduces a redundancy avoidance mechanism for multimedia traffic avoidance by taking advantage of multiple sink nodes. After that, authors of [14] focused on selecting and prioritizing forwarder list so that it becomes possible to enhance the transmission efficiency. Multi-sink aware operations were integrated into an opportunistic routing framework with an objective to reduce energy consumption. QMOR shows a significant performance increase in terms of energy consumption, delay and reliability. Since the paper exploits opportunistic routing, there is a great problem of overhearing in the network that can significantly decrease network lifetime due to the huge chunks of data.

Protocol proposed by Alaei and Barcelo-Ordinas facilitates multimedia node clustering that satisfies FoV constraints. In this routing approach, the main criteria to create clusters is the overlapped FoV of the two nearby sensor nodes. Given that the overlapped area of two multimedia sensor nodes is wide, the two sensors will act similarly from the coverage point of view and they are selected as members of the cluster. It is not necessary that nodes in the same clusters to be neighbors. The main aim of this clustering method is energy conservation and network lifetime prolongation through the creation of potential of cooperation among nodes belonging to the same cluster and avoiding redundant sensing and processing [19]. The proposed scheme does not compare performance results with any other similar or standardized protocol. Also, important routing metrics like packet delivery ratio or end-to-end delay were not considered. We call this protocol AB routing (Alae and Barcelo-Ordinas routing) for simplicity in this paper.

LEACH is distributed cluster formation algorithm. There are advantages for its being distributed but it offers no guarantee about the placement and/or number of CH nodes. Using a central control algorithm to form the clusters may produce better clusters by dispersing the CH nodes throughout the network. This is the basis for LEACH-C, a protocol that uses a centralized clustering algorithm and the same steady-state protocol as LEACH. Centralized scheme can be helpful for WMSNs because any bad organization in the cluster may lead to inefficient data acquisition. Readers can prompt to ref. no [20] for further description of LEACH-C.

Protocol proposed in [24] works in a distributed way to ensure the requirements of bandwidth and end-to-end delay for realtime data in WMSNs. Calculation of the delay bound is done based on propagation delay, transmission delay and switching delay. In [24], hop count has been used for dynamic bandwidth adjustment. The protocol confronts lesser amount of average delay and increases throughput by taking advantage of the multipath. The processing hubs reduce redundant data and unique channel allocation method facilitates lesser amount of collisions.

Zongwu *et al.* proposed a novel routing protocol for WMSN that uses a combined technique of game theory and genetic algorithm [25]. The forwarding policy is based on the certain QoS requirements like end-to-end delay, guaranteed bandwidth, maximizing network lifetime, etc. Mixed strategy Nash equilibrium game has been used in this protocol.

In [26], a clustered-control algorithm based on energy, location information, priority of coverage is proposed for WMSN. CHs are selected according to the geographical locations and remaining energy. The energy is conserved by putting a good number of sensor nodes into sleep when they are dealing with scalar data. This approach could successfully increase lifetime.

A geographic energy-aware multipath stream-based protocol (GEAMS) is proposed in [27] that can successfully alleviate energy hole problem. It is a multipath localized routing protocol that could increase energy efficiency and maintain QoS requirements simultaneously. Decision policy in GEAMS is based on the remaining energy at each neighbor, number of hops, distance between the nodes and its neighbors, history of the forwarded packets.

In [28], landmark adhoc routing protocol (LANMAR) was suggested to be used in WMSNs through the deployment of limited number of mobile swarms.

LANMAR can support high quality multimedia data in large scale sensor networks. The protocol can successfully resolve energy hole issue by directing a swarm of nodes to a certain area to assist data forwarding.

A routing protocol for WMSNs based on noninterfering disjoint multipath routing is proposed in [29]. It mainly addressed the problem of interference among multiple paths that use single channel. To overcome this challenge, authors of [33] suggested an on-demand approach that builds one path for a source node and additional paths are built when required in case of path congestion.

A new routing protocol for WMSN is proposed in [30] by modifying directed diffusion to facilitate WMSN with link quality and latency matrix. This routing protocol does not consider bandwidth as QoS metric for routing decision. The protocol achieves high-throughput for multimedia video streaming.

In [31], a geographic routing protocol named two-phase-greedy forwarding is presented (TPGF). It quests for shortest hole disjoint routing paths for WMSNs. TPGF uses multipath transmission through continuous exexution of the algorithm to find more on-demand routing paths. Nodes were location aware and had the information of each other's location in TPGF.

The real-time and energy aware routing (REAR) is a routing protocol for WMSNs that uses a set of metadata to find out routing paths instead of sensing realtime data [32]. Considering transmission delay and energy-efficiency requirements, an integrated cost function is designed to sort out the best route among the candidate routing paths. Unfortunately, the selected optimal routing path may not meet other QoS requirements like bandwidth and reliability. REAR can only be used for simple image transmission. It is not feasible for streaming multimedia data.

A new geographical multipath routing protocol called adaptive greedy-compass energy-aware multipath (AGEM) was proposed for WMSNs in [33]. It has two modes. They are smart greedy forwarding and walking back forwarding. The first mode is used where there is a neighbor node in the vicinity of the destination node. The positions of the sensor nodes in this step are used in such a way that selecting the next hop node would not require the knowledge of the entire topology. When a forwarding node totally becomes unable to transmit the packet to the destination, the walking back forwarding mode is used. AGEM outsmarts TPGF in terms of load balancing, energy consumption, packet loss ratio, and delay.

To find optimal routing path set for multiple WMSNs, an ant-colony-based routing protocol was proposed in [34]. As QoS parameters; bandwidth, delay, and packet loss rate are considered. Also, different video data is assigned with different priorities to sort out appropriate routing path. A set of paths that have lowest similarity and highest priority are chosen. The network throughput and data transmission performances are highly increased since the protocol obtained multipath mechanism. It suffers from high energy consumption because of maintaining routing tables and QoS metrics at each sensor nodes.

In [35], an angle-based differentiated services routing (ADSR) was proposed. ADSR chooses appropriate transmission region that is classified by the deviation angle of different types of data streams. Routes are chosen based on the local neighbor information like position of the neighboring nodes, residual energy level, and energy consumption.

The priority-based routing protocol for multimedia data delivery (PRMD) was proposed in [36]. There are three kinds of nodes in PRMD. They are visual sensor nodes, intermediate nodes, and sink node. The visual sensor nodes are used to capture image data, encode the data, and send the data to the sink nodes. Biggest portion of the nodes in PRMD is intermediate nodes that work as relays to forward the packets from the visual sensor nodes. Data packets are prioritized based on necessary QoS metrics and packets with high priority are sent faster.

To realize the trade-off among network lifetime, delay, and network utilization; an optimization problem is formulated based on network topology for WMSNs in [37]. The optimization problem is meant for cross-layer and decomposed into subproblems relating network lifetime, utilization, and transmission delay. The protocol is very complex because the complexity of the algorithm for cross layer optimization is very high.

In [38], a power-efficient multimedia routing (PEMuR) is proposed. It's a cluster-based routing protocol for WMSN. PEMuR mainly consists of two phases. They are: initialization phase and steady state phase. In the initialization phase, CHs are divided into two classes: upper level and lower level according to the distance calculated from the base station. The upper level CHs can directly connect to the sink node. Lower level CHs cannot reach sink nodes directly. They can do it in a multihop fashion. At the steady state phase, CHs are collected on the basis of their residual energy level. Nodes with higher residual energy level were selected as CHs. For huge video, the distortion prediction model in the routing scheme causes large amount of energy consumption.

In [39], a correlation-aware QoS routing (CAQR) algorithm is proposed. The protocol aims at minimizing energy consumption and satisfying other QoS constraints like transmission delay and reliability. The neighboring nodes share information and cooperate with each other to avoid data redundancy. A load balancing scheme is also proposed that helps avoiding congestion in the network by not allowing the sensed data to get transmitted in one routing path. CAQR however, does not consider any data aggregation technique.

An ant-based clustering protocol for WMSNs is proposed in [40]. The proposed protocol can be described in three steps. The first is to form clusters and select CHs. Nodes with high resources are encouraged to become CHs. In the second step, route discovery process starts. The proposed protocol uses special agent nodes to select robust routing paths according to the QoS requirements. In the last step, network traffic is forwarded using previously discovered path.

A multipath QoS aware routing (MQSR) protocol is has been developed in [41] for WMSN. The nodes in the network are divided into two subnetworks. Sensor nodes in the first subnetwork take part in route discovery occasionally. Sensor nodes in the second subnetwork are bound to take part in route discovery process. MQSR's network area is divided into cells. Every cell has a cell controller that controls other sensor nodes in the cell. The remaining nodes other than cell controllers form a simple sensor network that is responsible for data sensing and routing. The proposed MQRS protocol is highly suitable for large scale WMSNs and can increase network lifetime significantly.

In [42], an energy-efficient QoS assurance routing (EEQAR) for WMSNs was proposed. EEQAR can select trust-based neighbor nodes for data transmission. Communication behaviors are observed to evaluate neighbor nodes based on trust metrics like transmission delay, packet loss ratio, and reliability. Trust values represent quality of services that a sensor node can provide. For this reason, using trust value can ensure routing paths meet QoS requirements. Also, EEQAR can save a good amount of energy by periodically turning off the radios of the common sensor nodes. It has three kinds of nodes: sensor nodes, agent nodes, and sink node. Agent nodes work as CHs and have mobility.

For QoS-aware heterogeneous WMSN, a cross-layer-based clustered multipath routing (CCMR) is proposed in [43]. For selecting CHs, two performance metrics are considered: link quality and distance from the sender. To indicate these two metrics; hop count, received signal strength, signal-to-noise ratio and bit error rate are used. Every CH is responsible for checking the identity information of the sensor nodes joining the path to prevent path loops and cycles. In CCMR, packet delivery ratio and throughput are highly increased. Time-division multiple access is used for collision free multiple access.

Most routing protocols for WMSN are cluster-based. A hierarchical routing protocol is proposed in [44] that facilitates bidirectional communication between sensor nodes and CHs. First, shortest paths from the cluster members to CHs are discovered. After that, normal sensor nodes join the clusters and finally, they follow the proposed routing algorithm. On the basis of the position information of the nodes, each cluster node can find out other nodes that belong to the same cluster. All the neighboring nodes that may belong to the same cluster can create routing tables and discover shortest paths to their CHs. Cluster nodes cannot directly communicate with their CHs without joining permission. Creating routing table on a frequent basis is costly. That is why; a memory path is proposed in [48]. Also, sensor nodes can communicate with their neighbors only when it is necessary. This allows the protocol to have a decreased communication overhead.

A priority-based table-driven multipath routing algorithm named sequential assignment routing was proposed in [45]. Multiple paths are generated from the nodes to the sink node by creating multiple trees. The roots of these trees are one hop neighbors of the sink. After branching out all the discovered paths, the source node must choose one single path. Since this approach is mainly table driven, it requires good amount of memory which is not feasible for a resource constrained WMSN. Also, the protocol does not scale for the large-scale networks.

A real-time routing protocol for WMSNs that uses priority-based communication architecture was proposed in [46]. It can provide high level query and event services for distributed applications. The core policy of the proposed routing protocol is setting the deadline and distance aware priority for data packets. Data packets are generated from multiple the sources and they compete for shared communication channels. A significant decrease in the end-to-end delay can be observed in the proposed protocol [46].

Kim *et al*. proposed a routing protocol for heterogeneous WMSN that uses a hierarchical model [47]. It also uses a dual path from the sensing node to the base station. These two paths are: i) control path, ii) delivery path. To send data from the source node to the sink node via relays, the delivery path is used. Intermediate relay nodes are selected based on a cost function that depends on residual energy, distance, and bandwidth. Energy consumption rate is high in this protocol because two different types of paths must be discovered.

In [48], a mathematical model for QoS-aware route determination method for WMSN is proposed. The mathematical model is used to find optimal path for providing appropriate shared radio that satisfies the QoS for a wide range of real-time intensive media. To manage hop-by-hop switching in the proposed routing scheme, a mathematical model based on the Lagrangian relaxation method is used. Objective functions with embedded criteria are used to decide the pathway from the source to the sink node. The proposed routing protocol in [48] highly increases the packet received ratio, energy consumption, and average end-to-end delay compared to the other existing protocols.

A new routing mechanism for WMSNs based on software defined networking (SDN) technology is proposed in [49]. SDN can facilitate with the visibility of network resources and programmable interfaces. OpenFlow is widely used and is the most recognized realization of SDN. The proposed protocol in [49] is basically a QoS-aware routing mechanism for OpenFlow-enabled WMSNs. OpenFlow enable node will act as CHs and transmit data packets on behalf of the other sensor nodes. The protocol could achieve high throughput video/audio data.

A new multiobjective approach to solve the routing problem in WMSNs is proposed in [50]. Delay and the expected transmission count were considered as QoS requirements. Authors of [50] could avoid conflicts among the QoS parameters that may lead to suboptimal solutions.

The proposed EGC protocol is based on game theory and is a cluster-based routing protocol. That is why; in this section of the thesis, routing protocols that are either cluster-based or adopt game theory are comparatively analyzed. Table 1 presents a qualitative comparison among the routing protocols proposed for WMSN that are either cluster-based or adopts game theory.

Table 1. Qualitative comparison of the cluster and game-theory-based routing protocols.

Protocol	**Main features**	**Advantages**	**Limitations**
Ref. [21]	• Chooses appropriate paths for variant QoS requirements. • It is mainly based on data transfer between CHs and sink node where CHs transfer different classes of data.	• Faster convergence • Reduced overhead of the control messages	• Performance degrades due to bottleneck problem and respective use of optimal paths.
Ref. [17]	• Combines game theory and ant-colony algorithm. • Game theory is used to make the sensor nodes rational.	• Reduced overhead due to the use of game theory.	• No performance analysis and comparison with the existing state of art algorithms are presented.
Ref. [23]	• It is a nonlinear localization-oriented sensing model for WMSN. • It is based on clustering and exploits Montecarlo techniques	• Highly energy efficient. • Supports highly dense deployment	• No performance analysis and comparison with the existing state

	to estimate target locations cooperatively.	of the sensor nodes.	of art algorithms are presented.
Ref. [25]	• The forwarding policy is based on the certain QoS requirements like end-to-end delay, guaranteed bandwidth, maximizing network lifetime, etc. • Mixed strategy Nash equilibrium game has been used in this protocol.	• The bandwidth requirement is guaranteed. • The end-to-end delay requirement is satisfied.	• No in-depth formulation of game theory. • No performance analysis and comparison with the existing state of art algorithms are presented.
Ref. [26]	• CHs are selected according to the geographical locations and remaining energy. • The energy is conserved by putting a good number of sensor nodes into sleep when they are dealing with scalar data.	• Increased network life time and energy consumption.	• Energy consumption for data transmission is considered only. • Initial energy of the nodes is too small to support high chunks of data throughout the network lifetime.
Ref. [40]	• The proposed protocol can be described in three steps. The first is to form clusters and select CHs. • Nodes with high resources are encouraged to become CHs. In the second step, route discovery process starts. • The proposed protocol uses special agent nodes to select	• Higher reliability. • Fulfills the delay requirement.	• Multiple sink nodes have not been used. • Node mobility is not supported.

	robust routing paths according to the QoS requirements. • In the last step, network traffic is forwarded using previously discovered path.		
Ref. [43]	• For selecting CHs, two performance metrics are considered: link quality and distance from the sender. • To indicate these two metrics; hop count, received signal strength, signal-to-noise ratio and bit error rate are used. • Every CH is responsible for checking the identity information of the sensor nodes joining the path to prevent path loops and cycles. • Time-division multiple access is used for collision free multiple access.	• Flexible time slot assignment for CH. • Several routing metrics have been considered for performance analysis like end-to-end delay, throughput, packet delivery ratio, etc.	• A threshold could have been used in network configuration for better cluster formation
Ref. [44]	• First, shortest paths from the cluster members to CHs are discovered. • After that, normal sensor nodes join the clusters • Finally, they follow the proposed routing algorithm. • Based on the position information of the nodes, each cluster node can find out other nodes that belong to the same cluster.	• Reliable multihop routing using least amount of resources • Nodes do not have to wait for CHs to send them join requests.	• Distributed cluster arrangement may lead to bad cluster formation.

Among the compared protocols, [17] and [25] are game-theory-based. Both protocols do not present any performance comparison with the state-of-the-art protocols. Also, detailed formulation of game theory and how it helped increase the performance of the proposed protocols are not presented. Other protocols referred in Table 1 are cluster-based. Even though the referred protocols ([21, 23, 26, 40, 43, 44]) could increase network lifetime and reduce energy consumption, they did not have any cluster head selection and data redundancy avoidance method.

III. NETWORK MODEL AND PROBLEM STATEMENT

We need some assumptions regarding the sensor nodes and the network model. Our first assumption is that every single node has enough power to transmit to the sink nodes. We also assume that the nodes have ability to vary their transmission power and support different established MAC protocols. We will use a model in which we always have data to send and nearby nodes have co-related data. In this section of the paper, we describe the network model and the problem statement for the proposed protocol. We will describe our network model further and mathematically formulate the problem statement.

A. Network Model

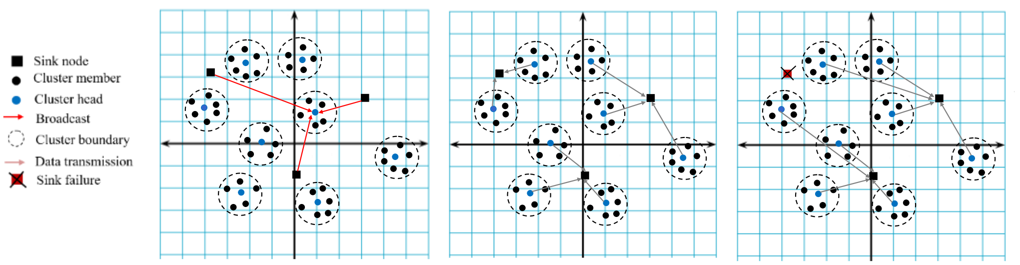
For our network model, we consider a 100m ×100m network space where multimedia sensor nodes are randomly and uniformly scattered. In clustered sensor networks, there are three kinds of nodes: CH nodes, CM nodes, and sink nodes.

CH nodes: These are nodes that will be responsible for communication with the sink nodes. They will receive the gathered data from other member nodes in the cluster and will not participate in data acquisition during the period they act as CHs. Role of being a CH will rotate and will be selected optimally using game theoretic computations. There will be a limited number of the CHs in the network adhering to other member nodes in the cluster that are lying within the range.

CM nodes: These are the nodes that are responsible for data gathering from the network. Periodically they report to the CHs and do not transmit data to the sink nodes directly. For our network, CMs compete for the FoV of the object and depending on their energy level, one of the two competing nodes wins and transmits the data to the CH.

Sink nodes: These are the nodes that receive data from the CHs and have higher power level and computation capacity. Sink nodes also act as a gateway to connect to the outer world and users may directly request data fetching from them remotely. There are three sink nodes in the network. CHs transmit data to the sink nodes based on the distance.

Multi-sink network architecture: Figure 1(a), 1(b), and 1(c) present network scenarios where multiple sink nodes have been deployed. In Figure 1 (a), sink nodes are broadcasting to the CH node of CH and based on the RSSI value, the CH will decide which sink it should choose to send the gathered data. In Figure 1(b), CHs in different clusters are sending data to their nearest sink node for faster and reliable data delivery. The dashed circles represent a cluster, black circular nodes represent CMs, blue circular nodes represent CHs and the quadrilaterals represent sink nodes. Role of a sink node is of utmost importance in a WMSN as the entire network is useless without it. Failure of the sink node is not desired and using multiple sink can increase reliability greatly. Figure 1(c) shows that even if a sink node fails/ runs out of energy, the WSN can carry on its task.



(a) Multiple sink nodes broadcasting to all the CHs.

(b) CHs sending data to the nearest sink node

(c) An example scenario of a sink failure.

Figure 1: Example network scenarios.

B. Problem Statement

In this subsection, the problem is formally defined for developing a clustering protocol based on evolutionary game for WMSNs with multiple sinks. The main goal of the proposed protocol lies in electing CHs using EG. The first problem statement describes this phenomenon mathematically for the convenience of readers. Another contribution of EGC is the data redundancy avoidance method to efficiently manage the high data volume in WMSNs. The second problem statement describes this goal.

Problem statement 1: Given a set of sensor nodes in the network, $S = \{s_1, s_2, \ldots, s_n\}$, our goal is to find out:

- The number of clusters k.
- A set of CHs determined using EG, $H = \{h_1, h_2, \ldots, h_k\}$, and k clusters $C_1 = \{h_1\}$, $C_2 = \{h_2\}$, …, $C_k = \{h_k\}$. Here, H is the set of CHs and $h_1, h_2, \ldots, h_k$ are the CH nodes in cluster H. $C_1, C_2, \ldots, C_k$ present different clusters in the network.
- A set of CMs determined using EG, $M = \{m_1, m_2, \ldots, m_k\}$. Here, M is the set of CMs and $m_1, m_2, \ldots, m_k$ are the CM nodes in a cluster.

Problem statement 2: Given that $M = \{m_1, m_2, \ldots, m_k\}$ and number of sensor nodes, $n \leq 100$, our goal is to find out

- The overlapped region between two nearby sensor nodes (for example m_1 and m_2) to choose one from the two based on the average residual energy if the overlapped area A, crosses a certain threshold T.
- If the data captured (still images for our case) by one sensor node is identical to another based on their overlapped FoV to avoid transmission of same kind of data.

IV. EVOLUTIONARY-GAME-BASED CLUSTERING PROTOCOL

In this section, a robust clustering protocol called EGC for WMSNs with multiple sinks is presented, which is based on evolutionary game. Clustering technique can save a lot of energy in WMSNs as well as conventional WSNs because the network performance is significantly improved by decreasing the number of hops from the sensor nodes (SNs) to sink node and reducing the amount of data to be delivered [51]. In cluster-based networks, more energy is consumed by CH nodes rather than the normal SNs (which can also be regarded as cluster members). It is obvious because more computing and communication loads are assigned to CHs [52]. The variance of the energy consumed by nodes being CHs and CMs may result in unexpected early death of some nodes. LEACH is the most famous clustering protocol that can resolve this kind of energy imbalance [20].

In EGC, nodes will organize themselves into clusters based on overlapped FoV. One node will act as CH and other CMs will send gathered data to CH. CHs will send data to sink nodes after some processing. Therefore, energy expenditure of the CH nodes is higher than the CM nodes. Operation of EGC protocol can be divided into rounds as discussed earlier (“setup” and “steady-state” phase). In “setup” phase, clusters are formed, CH nodes are selected intelligently using EG, CHs advertise to the CMs within the cluster and CMs send join request to the CHs. In “steady state”, CHs decide which sink to transmit data based on the RSSI value. Finally, a data redundancy avoidance algorithm is used before processing and transmitting data to the sink nodes by CHs. Figure 2 describes the traditional rounding system used in our EGC protocol. Additionally, Table 2 describes the operations in two states of a round in EGC.

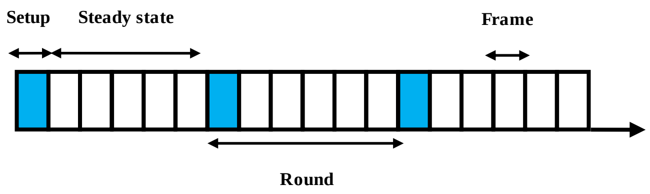


Figure 2: Setup and steady-state phases of EGC.

Table 2. Detailed operation of the setup and steady state phase.

Phase	Operation
Setup	1. Cluster Formation. 2. Intelligent selection of CH nodes using game theory. 3. CHs advertise to CM. 4. CMs send join request to CHs.
Steady state	5. Sink nodes broadcast to CHs. 6. CHs decide which sink to transmit data based on the RSSI value. 7. Use of Data redundancy avoidance algorithm. 8. Data transmission.

We will describe the entire process of the proposed protocol in the coming sections. Section A will describe the cluster formation technique, section B will elaborate the CH election process, section C will describe our data redundancy avoidance algorithm along with proposed EGC algorithm.

A. Cluster Formation

Multimedia sensors like cameras have directional views and can capture multimedia data based on that. Multimedia sensor nodes deployed randomly and densely with fixed lenses (having a certain angle) are assumed here. It is because most of the current WMSN platforms (like SensEye and Panotes) have fixed lenses. It is also assumed that sensors are aware of their positions. All the sensor nodes must be equipped to have the information of their location coordinates and orientation. Any lightweight localization techniques can be used in this case. We have mentioned about overlapping area in the previous portion of the paper and now would like to introduce a term threshold *(T)*. It is nothing but the minimum percentage of the overlapped region for FoV. This threshold will be used to define cluster formation process. It will denote the minimum percentage of the overlapped region between sensor nodes' FoV for membership inclusion in the cluster. Figure 3 presents the FoV of a multimedia sensor node.

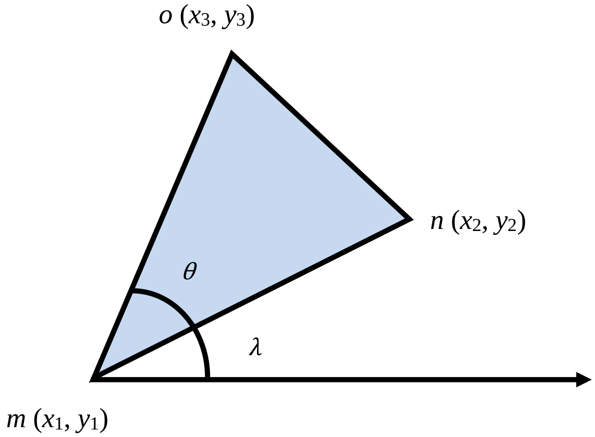


Figure 3: FoV of a camera in a multimedia sensor node.

In Figure 3, we can assume the FoV to be an isosceles triangle having two congruent sides. The vertex angle can be represented as theta (θ). Length of the congruent sides can be denoted as $mn = C_s$. The orientation angle can be λ. Let us also assume, the sensor is located at point $m\ (x_1, y_1)$. To find the coordinates of *"n"* and *"o"* points, following formulations can be undertaken:

$$x_3 = x_1 + C_s.cos(\lambda). \tag{1}$$

$$y_3 = y_1 + C_s.sin(\lambda). \tag{2}$$

$$x_2 = x_1 + C_s.\cos\big((\lambda + \theta)mod2\pi\big). \tag{3}$$

$$y_2 = y_1 + C_s.\cos\big((\lambda + \theta)mod2\pi\big). \tag{4}$$

If we know the coordinates of a triangle, it requires simple matrix operations only to compute the area. It is necessary because a certain portion of the area (1/2 or

3/4) of the triangle is to be defined later as threshold in our cluster formation technique and data redundancy avoidance algorithm. There are three possible geometrical shapes that can be noted by observing overlapping FoVs of two closely placed multimedia sensor nodes. They are triangle, quadrilateral and polygon. Fig. 4 describes different shapes of the overlapped area. The shaded regions represent the overlapped area in the figure.

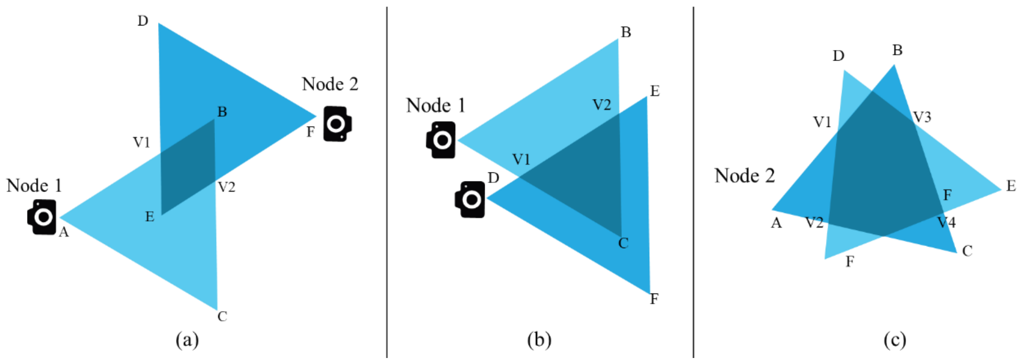


Figure 4: Different geometric shapes that can cause due to overlapped FoV.

Threshold, *T* can be defined as half of the area of the triangle created because of the FoV of a sensor node. Nodes lying close to a sensor node having overlapped FoV greater than the threshold can be in the same cluster. For example, nodes in Fig. 4(a) cannot belong to the same cluster but nodes in Figure 4(c) may belong to the same cluster. For EGC, algorithm to form the cluster is executed in a centralized way via sink nodes. Reasons to choose this centralized architecture are:

- If the architecture is distributed, each node must notify the rest of the nodes about its location and orientation.
- The sink nodes can be provided with adequate amount of resources like storage, power supply etc. Since normal nodes are more resource constrained, sink nodes can play this role better.
- Information collection through the sink node is more power efficient than collecting and spreading this information to each node in the network.

- Our optimal cluster election process using EG requires nodes in the clusters to be divided based on their remaining energy. This is done using the sink node.
- Finally, using a centralized scheme can relieve the processing load from the sensors and network lifetime.

To form a cluster, first, the sink creates an empty cluster by associating an un-clustered sensor node. The node will be the first member in the cluster. After this, the sink finds the CMs by computing the overlapped area and comparing it with the threshold. When no more nodes can be added to the cluster, the sink takes a new un-clustered node and begins the cluster formation process again. Each CH elected using EG must broadcast an advertisement (ADV) message. The message is segmented into node's ID and a header that makes this message distinguishable as an announcement message. When the CMs have decided which clusters they will join, they must inform the elected CHs about their membership in the clusters. Each CM node sends a join request to a CH. The join request message contains the "node ID" and "CH ID". If a node receives more than one ADV message, it joins the CH with the highest energy. In a rare case, a CM node may not receive an ADV message. In this case, it can either keep itself aloof from any kind of data acquisition or declare itself as a CH based on the remaining energy it has.

B. CH Election Process Using Evolutionary Game Theory

In this section of the paper, we elaborately discuss the process of optimal CH election using EG. Being a CH decreases the energy level more than being CM. Being a CM will increase the lifetime of a node. Being a CH decreases the lifetime of a node but of all the nodes decide to remain CM, the network will lose the cluster-based functionalities. The evolutionary game designed and formulated to elect CHs had three essential components. It is modeled as: E_G (P, S, U), where P represents a set of players, S represents a set of strategies and U represents the utility function.

P consists of sensor nodes that act as players of the game. $P = \{p_1, p_2, p_3, \ldots, p_n\}$; where $p_1, p_2, p_3, \ldots, p_n$ are sensor nodes in the cluster. These nodes in set P is classified in to two subsets

$$P = NH \cup NL, \tag{5}$$

where NH is a set of nodes that have higher level of residual energy compared to a certain energy threshold (E_T), NL is a set of nodes that have lower remaining energy compared to E_T, and $NH \subset$ P, $NL \subset$ P. The strategy set, S has two elements

$$S = \{T_{CH}, T_{NCH}\}, \tag{6}$$

where T_{CH} presents the strategy of being a CH and T_{NCH} presents the strategy of not being a CH. As mentioned earlier, U presents the utility function, the basic function to calculate utilities can be presented by the following equation

$$U_i = R_i - P_i, \tag{7}$$

where i represents the node we are calculating the utility of, R_i and P_i are the reward and penalty for node i based on the action it chooses while playing the game. Using equation (7), complex utility functions for nodes falling under NH and NL sets will be formulated. In EG, finding out evolutionary stable strategy (ESS) is a crucial part. ESS ensures different species in a population to co-exist together and not threatening each other by increasing extinction probability through selfish choice of strategies. For the game designed in our protocol EGC, ESS for CH election game is T_{CH} for nodes in NH subset and T_{NCH} for nodes in NL subset. Table 3 presents the description of the parameters and notations used to formulate the CH election game.

Table 3. Symbols used to formulate CH election game.

Symbol	Description
α	The reward to be given to a node in set *NH* if they become CHs.

β	The reward to be given to a node in set *NL* if they become CHs.
δ	The step of encouragement or discouragement for being a CH.
ρ	The rate of nodes in *NH* set to select T_{CH} strategy.
η	Rate of nodes in *NL* set to select T_{CH} strategy.

If the rate of nodes in set *NH* to become CHs (selecting T_{CH} strategy) is ρ, the rate of them to become CMs (selecting T_{NCH} strategy) is $(1-\rho)$. This condition is also true for nodes in set *NL*. Therefore, the rate of nodes in set *NL* to become CHs (selecting T_{CH} strategy) is η and the rate of them to become CMs (selecting T_{NCH} strategy) is $(1-\eta)$. Based on all these assumptions, the expected utility for nodes in set *NH* to become CHs by choosing T_{CH} strategy is expressed as follows

$$U_{NH(CH)} = \eta\alpha + (1-\eta)(\alpha + 2\delta) = \alpha + 2\delta - 2\delta\eta \tag{8}$$

The utility of nodes in *NH* set to become CMs by choosing T_{NCH} strategy is

$$U_{NH(NCH)} = \eta(\alpha-\delta) + (1-\eta)(-\delta) = \eta\alpha - \eta\delta - \delta + \eta\delta = \eta\alpha - \delta. \tag{9}$$

Therefore, the total revenue for nodes in set *NH* is expressed as

$$\overline{U_{NH}} = \rho(\alpha + 2\delta - 2\delta\eta) + (1-\rho)(\eta\alpha - \delta). \tag{10}$$

In EG, the change of rate of players' action is called replicator dynamics. After mathematical analysis, the replicator dynamic equation for nodes in *NH* set is obtained by the following equation

$$F(\rho) = \frac{d\rho}{dt} = \rho\left[U_{NH(CH)} - \overline{U_{NH}}\right] = \rho(1-\rho)[\alpha + 3\delta - \eta(2\delta - \alpha)]. \tag{11}$$

In a similar fashion, equations to calculate utility for nodes in *NL* set is formulated. Equation (12) and (13) subsequently present the utility of nodes in *NL* set to become CHs by choosing T_{CH} strategy and the utility of nodes in NL set to become CMs by choosing T_{NCH} strategy.

$$U_{NL(CH)} = \rho\beta + (1-\rho)(\beta+\delta) = \beta + \delta - \rho\delta. \tag{12}$$

$$U_{NL(NCH)} = \rho(\beta+2\delta) + (1-\rho)(-\delta) = \beta\rho + 3\rho\delta - \delta. \tag{13}$$

Therefore, the total revenue for nodes in set NL is expressed as

$$\overline{U_{NL}} = \eta(\beta+\delta-\rho\delta) + (1-\eta)(\beta\rho + 3\rho\delta - \delta) \tag{14}$$

The replicator dynamic equation for nodes in NL set is formulated as

$$\frac{d\eta}{dt} = H(\eta) = \eta\left[U_{NL(CH)} - \overline{U_{NL}}\right] = \eta(1-\eta)\left[\beta + 2\delta - (\beta+4\delta)\rho\right]. \tag{15}$$

Figure 5 presents the utility matrix for the formulated game. It shows the amount of reward a node in NH and NL sets gets by choosing either T_{CH} or T_{NCH} strategy.

		NL	
		T_{CH}	T_{NCH}
NH	T_{CH}	(α, β)	$(\alpha+2\delta, \beta+2\delta)$
	T_{NCH}	$(\alpha-\delta, \beta+\delta)$	$(-\delta, -\delta)$

Figure 5: Utility for choosing variant strategies in the designed game.

When nodes get divided into clusters, it is necessary to classify them in to *NH* and *NL* sets. All the nodes in different clusters send an initial message to the sink node. This message contains two information. One is node ID, and another is the residual energy level of the node, N_{RE}. The sink node sorts out the nodes based on the N_{RE} of the node. A median value is selected as E_T which represents the energy threshold. Sink node broadcasts this value to the nodes in different clusters. All the nodes in the clusters divide themselves into either *NL* or *NH* sets based on the threshold value. After that, utilities are calculated using equations (10) and (14) presented earlier. Because of the calculated utilities, nodes either decide to be CH or CM by choosing T_{CH} or T_{NCH} strategies.

C. Data Redundancy Avoidance and EGC Algorithm

In previous sections, we have discussed about the overlapped regions of FoV created due to the closely placed multimedia sensor nodes. We have also introduced the term threshold *T*, which is the certain portion (for our case we assume it to be half) of the isosceles triangle of the FoV. The congruent sides of the triangle are denoted by C_S. Our observations show that if any object falls in to the FoV of two closely placed sensor nodes and the FoVs of them create a polygon, the data will be redundant if both nodes send the snapshot of the object. If any object falls within the shaded region in Figure 6, FoV for that object to node 1 and node 2 is almost similar. For geometric shapes like triangle and quadrilateral, we cannot be sure if the overlapped area is big enough to cross the threshold value *(T)* or small enough to be under the threshold. Triangles or quadrilaterals created due to the overlapped FoV can be as small as we can see in Figure 7(a) or as big as it is in Figure 7(b).

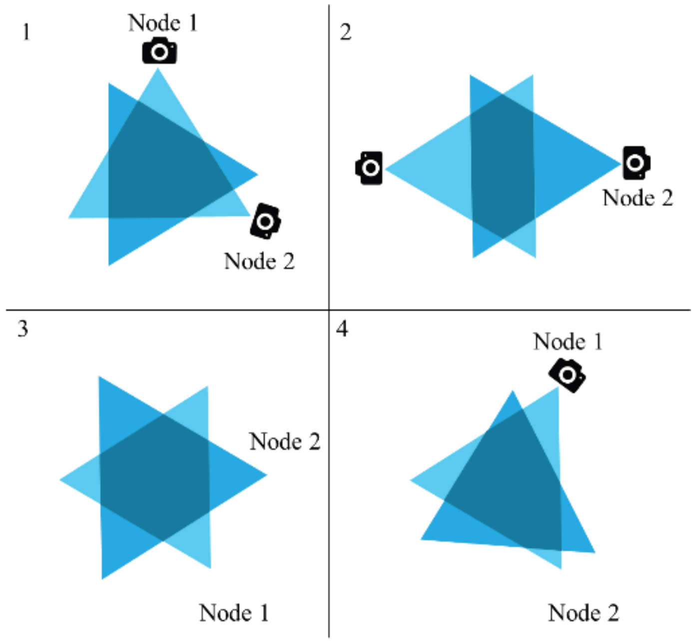


Figure 6: Different types of polygons created by the overlapped FoVs of two closely placed sensor nodes.

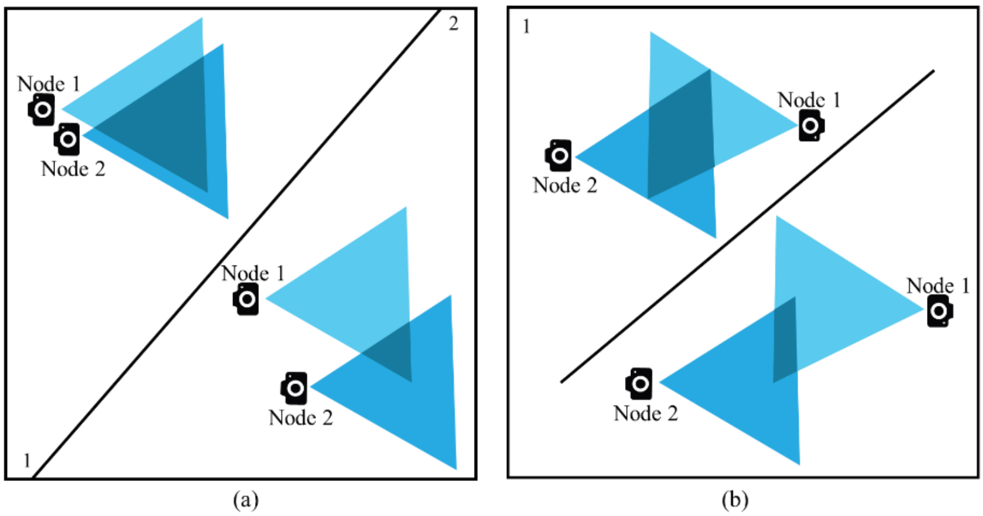


Figure 7: Different sizes of (a) triangles and (b) quadrilaterals created due to Overlapped FoV.

Based on all these assumptions and interpretations, our data redundancy avoidance algorithm is:

In this subsection, the problem is formally defined for developing a clustering protocol based on evolutionary game for WMSNs with multiple sinks. The main goal of the proposed protocol lies in electing CHs using EG. The first problem statement describes this phenomenon mathematically for the convenience of readers. Another contribution of EGC is the data redundancy avoidance method to efficiently manage the high data volume in WMSNs. The second problem statement describes this goal.

Algorithm 1: Data redundancy avoidance

---

1. Node 1 → n_1, Node 2 → n_2
2. Residual energy of n_1 → R_1, Residual energy of n_2 → R_2
3. Initialize threshold = T
4. Check if the Euclidian distance between two nodes, $D > 2C_s$
5. **if** ($D > 2C_s$)
6.   No overlapping FoV exists
7. **end if**
8. **while** ($D \leq C_s$)
9.   **if** geometrical shape is polygon
10.   data is redundant
11.   **end if**
12.   **if** geometrical shape is quadrilateral || triangle
13.   compute the area of the quadrilateral triangle
14.   **end if**
15.   **if** (Area > T)
16.   data is redundant
17.   **else**
18.   data is not redundant
19.   **end if**
20. **end while**
21. **if** ($R_1 > R_2$)
22. n_1 will own the object's FoV and transmit to CH accordingly
23. **else**
24. n_2 will own the object's FoV and transmit to CH accordingly
25. **end if**

If the distance between two nodes is twice greater than the congruent sides of the FoV created by them, it is impossible to have a FoV overlap. Now, if the case is not like this, we can conclude that there is a possibility of data redundancy. In this algorithm, we consider data to be redundant if the area created by the two FoV overlaps forms a polygon. If it either forms a triangle or a quadrilateral, we must compute the area of that and compare it with the threshold to determine if the data is redundant. If a view of an object is found to be same by two nodes, node with higher energy will win the FoV and pass the data to CH.

The data redundancy avoidance algorithm and optimal CH selection procedure using EG are the core mechanisms of the proposed EGC protocol. The entire process can be viewed in the following flow diagram:

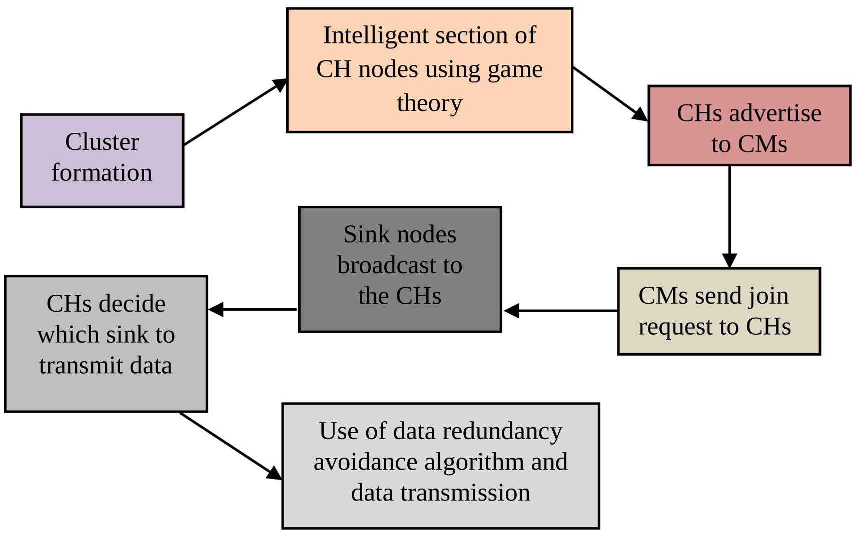


Figure 8: Overall process in the proposed EGC protocol.

EGC's architecture is like LEACH but the core differences are: 1) cluster formation using the FoVs of the multimedia sensor nodes, 2) data redundancy avoidance using the overlapped FoVs of the sensors, and 3) optimal CH election using EG. The algorithm for the proposed protocol is given below:

Algorithm 2: EGC Algorithm

Setup phase:
1. ***Initialize*** X to be the set of nodes ($X = \{X_1, X_2, X_3, \dots, X_n\}$)
2. Number of CHs → Y
3. Highest number of nodes to be in cluster → H
4. Number of rounds → I_n
4. Final Round → I_f
5. Threshold Area → T
6. T = ½ (Area of the isosceles triangle created by FoV)
7. **loop** until every single node is put at least into one cluster
8. Empty cluster creation by associating an unclustered node
9. X_n → First member of the cluster
10. Overlapped area computation between X_n and →$X_{n \pm m}$
11. **while** (number of nodes in the cluster < H)
12. **if** (Area calculated > T)
13. $X_{n \pm m}$ is added to the cluster (m = any integer)
14. **else**
15. Consider another node for cluster formation
16. **end while**
17. **end loop**
18. Decide the CHs using EG
19. Advertise as CHs to the CMs within the cluster

Steady-state phase:
20. Sink nodes broadcast to the CHs.
21. CHs decide which sink to transmit based on the RSSI value.
22. Avoidance of data redundancy using Algorithm 1.
23. CMs send data to the CHs.
24. CHs deliver data to the nearest sink node.
25. Repeat the whole process until final round (I=I_f).

V. PERFROMANCE EVALUATION

In this section, the performance of the propsoed EGC is evaluated via computer simulation and then compared to the conventional protocols. We compare the propsoed EGC with QMOR, AB routing [19], and LEACH-C [20]. Like EGC, QMOR considers multiple sinks and data redundancy avoidance. AB routing have clustering mechanism along with data redundancy avoidance in WMSNs. LEACH-C is the most used clustering-based protocol for centralized WSNs, and it is selected for performance study for investigating how our proposed protocol performs against a real-time protocol currently getting widely used in the industry. For simulation, the experimental environment for wireless multimedia sensor networks built upon Castalia/Omnet++ called WISE-MNet is used.

A. Simulation Environment

To evaluate perfromance of our proposed EGC protocol in a certain simulation environment, it is necessary to adopt some routing metrics based on which a comparative analysis is conducted. Routing metrics are defined as measures used by routing protocols to make routing decisions [53]. Routing protocols use different routing metrics to choose the best routing path starting from the source to the destination. The quality of a routing path is indicated by the routing metrics. We will consider four routing metrics to compare the performance of EGC with the existing works. They are namely average residual energy, average end-to-end delay, network lifetime and average packet delivery ratio. The routing metrics are defined as follows:

- Average residual energy is the average remaining energy of a node after a certain simulation time.
- Network lifetime is the elapsed time until half of the nodes are alive.

- Average end-to-end delay is the average time required for a packet to reach its destination from source.
- Average packet delivery ratio is the ratio of the received packets over packets sent in the network.

The simulation environment consists of 100m×100m network space. For simulation we have considered a random deployment of 100 multimedia sensor nodes. The environment consists of a moving target. Still images are captured by the nodes who win FoVs of the target component. Each node has an initial energy of 2 Joules and can sense up to 30m. Table 4 summarizes the simulation environment for the deployment of the proposed protocol.

Table 4. Simulation parameters.

Parameter	Value
Network Space	100m×100m
Transmission Range	15m
Number of sensor nodes	100
Data rate	2Mbps
Image size	176×144
Frame rate	30fps
Offset angle	60 degree
Sensing radius	30m
Initial energy of each node	2J

Table 5 summarizes the energy expenditure of a multimedia node for some basic operations.

Operation	Value
Camera initialization	1725.4 mj
Frame grabbing	537.2 mj
Object recognition	144.2 mj
Shutdown	768.5 mj

In this section of the paper we will use some symbols for mathematical foundation and analysis. Table 6 lists the symbols with their intended meaning that are going to be used in this section.

Table 6. Symbols used and their meaning.

Symbol	Description
RE_i	Residual energy of any node *i*.
Tx_{avg}	Average number of packets transmitted.
DT_{CH_i}	Data packets transmitted by any CH in the network.
PDR_{avg}	Average packet delivery ratio.
Rx_{sink}	Data received by the sink node.

B. Simulation Results and Discussions

Average Residual Energy: Figure 9 shows the decrease of avreage residual energy of the sensor nodes in different protocols. X axis represents the simulation time in seconds and Y axis represents the average residual energy. From Figure 9, it can be seen that the energy is depleted faster in QMOR rather than LEACH-C. The reason behind this is QMOR is mainly based on opportunistic routing and maintains a forwarding list of nodes capable of transmitting the data. In QMOR, a set of nodes is selected as potential forwarders. The forwarding candidates that receive the transmitted packet coordinate among each other to decide which of them must forward the packet and which must discard it. This phenomenon is mainly responsible for faster energy depletion. Energy consumption for both data receiving and transmission were summed and averaged in each round to calculate the average residual energy. LEACH-C is cluster-based routing and there is no such issue of selecting candidate forwarding nodes among which some may even drop data packets. Also, for certain frames, data is sent to the sink node directly in QMOR which is also not energy efficient. On the other hand, AB routing uses a simple mechanism of clustering based on the FoVs of the nodes and redundant transmissions are avoided. Since the protocol is clustering based, number of transmissions are reduced, and it performs better than LEACH-C because of the reduction in redundant transmission avoidance mechanism. Lastly, EGC, proposed protocol in this paper performs better than other three algorithms. Obvious reasons behind this are the inclusion of a more efficient redundancy avoidance algorithm, optimal CH selection using game theory and inclusion of multiple sink nodes that helped nodes to avoid long distance transmissions. Also, it performs better than AB routing due to the optimal CH election process using EG. If the residual energy of any node i is RE_i at a time t, the average residual energy (for 100 nodes) is calculated using the following equation

$$Average\ residual\ energy\ (t) = \frac{\sum_{i=1}^{100} RE_i}{100}. \tag{16}$$

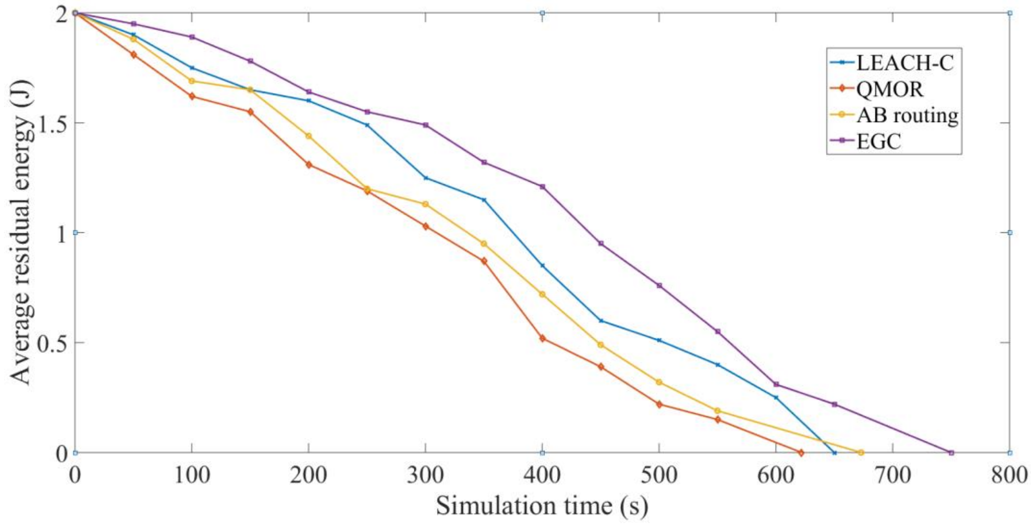


Figure 9: Average residual energy.

Network Lifetime: Figure 10 presents a comparative graph in terms of the number of living nodes during simulation. X-axis represents the simulation time and Y-axis represents the number of living nodes in the simulation time. AB routing performs better than LEACH-C in terms of network lifetime because it has a cluster formation process based on FoV. As mentioned earlier, the network lifetime is considered as the time when half of the nodes die, we can see that EGC performs better than other two protocols when the number of living nodes is 50. It is mainly because of the optimal CH election game used elect CHs and multiple sink nodes.

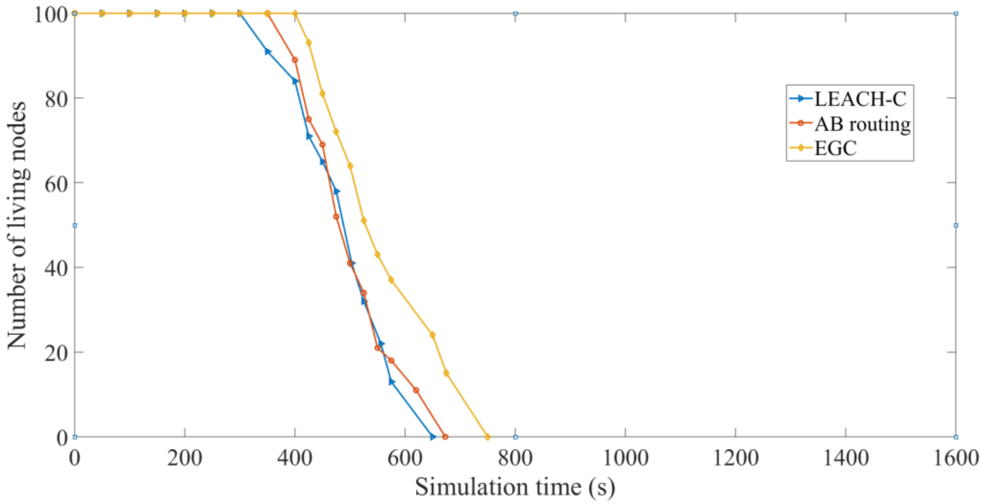


Figure 10: The number of living nodes showing network lifetime.

Average End-to-End Delay versus the Number of Nodes: Simulation results were obtained for EGC in terms of end-to-end delay too. Number of nodes was increased in different rounds and the average end-to-end delay was observed. Delay is lesser in QMOR than LEACH-C. The main reason is the direct transmission of certain data packets from source node to sink node. Also, once priority based forwarding list is established in QMOR, delay is decreased. From Figure 11, we can also see that EGC performs better and shows lesser amount of delay (ms) than QMOR and AB routing [40]. Use of multiple sink nodes and direct one hop transmission from the CHs to the closest sink nodes is the main reason for such performance increase.

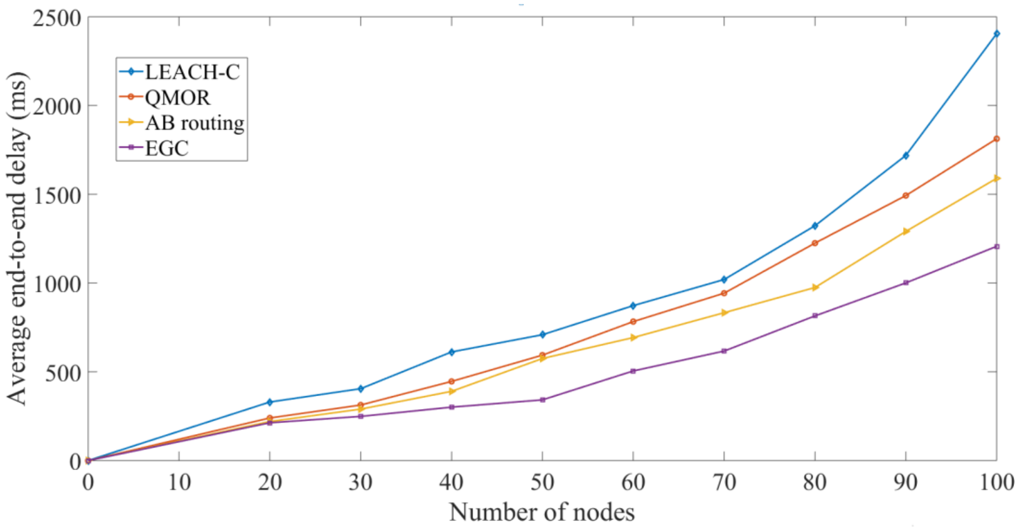


Figure 11: Average end-to-end delay vs. the number of nodes.

Packet Delivery Ratio: For this routing metric, we considered transmissions of the CHs to the sink node/s. To calculate the average packet delivery ratio, first we summed the number of data packets sent by each CHs. Assuming that there are N number of clusters in the network, we found out the average of packets transmitted using the following equation

$$Tx_{avg} = \frac{\sum_{i=1}^{N} DT_{CH_i}}{N}, \tag{17}$$

where Tx_{avg} is the average number of packets transmitted to the sink node, DT_{CH_i} is the data packets transmitted by any CH in the network. Finally, the average packet delivery ratio is calculated using equation (18)

$$PDR_{avg} = \frac{Tx_{avg}}{Rx_{sink}}, \tag{18}$$

where PDR_{avg} is the average packet delivery ratio, Rx_{sink} is the data received by the sink node. Since there are multiple sinks in EGC, equation (18) is not applicable for it. To calculate the PDR_{avg} for EGC, equation (19) has been used:

$$PDR_{avg} = \frac{Tx_{avg}}{\left(\frac{Rx_{sink1} + Rx_{sink2} + Rx_{sink3}}{3}\right)}, \quad (12)$$

where Rx_{sink1}, Rx_{sink2} , and Rx_{sink3} are the data received by the three sink nodes used in EGC.

QMOR is an opportunistic routing protocol. EGC, AB routing and LEACH-C are clustering based routing protocols. It is not feasible to compare an opportunistic routing protocol with cluster-based routing protocols since the packet delivery ratio will always be high on opportunistic routing. That is why; we have excluded it from the performance comparison for this routing metric. We have calculated the average packet delivery ratio every 100 second in the simulation time and plotted the graphs for EGC, AB routing and LEACH. Since there are multiple sink nodes in EGC, congestion probability is very low in it. EGC had highest amount of average packet delivery ratio compared to LEACH and AB routing. Fig. 13 presents the performance comparison of the three protocols in terms of average packet delivery ratio. The X-axis represents the simulation time and the Y-axis represents the average packet delivery ratio. We can observe that EGC outperforms other two protocols in the figure.

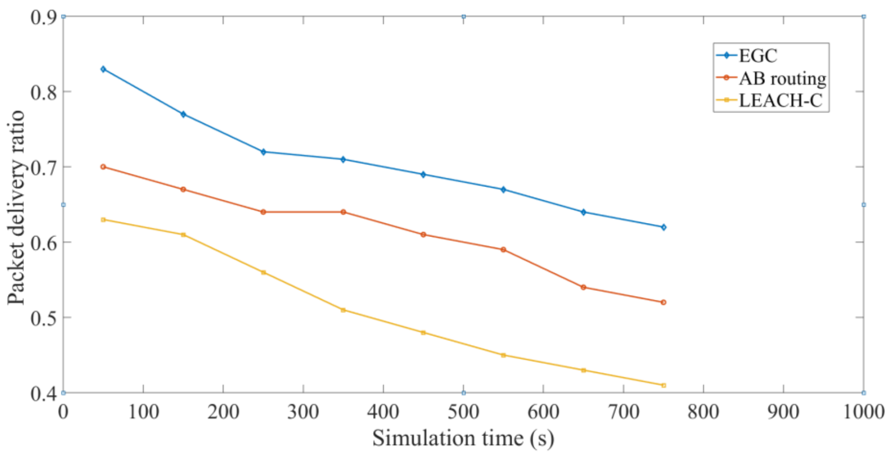


Figure 12: Packet delivery ratio.

VI. CONCLUSIONS

In WMSNs, energy efficiency is a critical design issue because energy should support to deliver the high volume of data along with a certain requirement of end-to-end delay. Such an issue makes designing a routing protocol for WMSNs more challenging. In this paper, we have proposed a new clustering protocol for WMSNs, which is based on clustering technique using EG. The proposed EGC overcomes the challenge by introducing a data redundancy avoidance algorithm and intelligent CH election uisng EG in WMSNs with multiple sinks. Our extensive performance study shows that the EGC protocol achieves lower energy consumption, longer network lifetime, shorter end-to-end delay, and higher packet delicvery ratio compared to QMOR, AB routing, and LEACH-C. In summary, it can be concluded that EGC is more suitable for WMSNs that intend to facilitate survellance systems subjected to stringent QoS requirements. EGC can be deployed for environmental and battlefield monitoring where faster data delivery is needed.

These days unmanned aerial vehicles (UAVs) are used as sink nodes for efficient data collection in sensor networks. Implementing the proposed EGC protocol to investigate how the clustering scheme performs when UAVs are used as sink nodes is one of our future works. Also, there is a plan to investigate how the proposed clustering protcol works when large number of densely populated sensor nodes are involved in the network area.

BIBLIOGRAPHY

[1] I. Akyildiz, T. Melodia, K. Chowdhury, A survey on wireless multimedia sensor networks, Computer Networks. 51 (2007) 921-960. doi:10.1016/j.comnet.2006.10.002.

[2] R. Dai, I. Akyildiz, A Spatial Correlation Model for Visual Information in Wireless Multimedia Sensor Networks, IEEE Transactions On Multimedia. 11 (2009) 1148-1159. doi:10.1109/tmm.2009.2026100.

[3] R. Dai, P. Wang, I. Akyildiz, Correlation-Aware QoS Routing With Differential Coding for Wireless Video Sensor Networks, IEEE Transactions On Multimedia. 14 (2012) 1469-1479. doi:10.1109/tmm.2012.2194992.

[4] I. Akyildiz, T. Melodia, K. Chowdury, Wireless multimedia sensor networks: A survey, IEEE Wireless Communications. 14 (2007) 32-39. doi:10.1109/mwc.2007.4407225.

[5] I. Almalkawi, M. Guerrero Zapata, J. Al-Karaki, J. Morillo-Pozo, Wireless Multimedia Sensor Networks: Current Trends and Future Directions, Sensors. 10 (2010) 6662-6717. doi:10.3390/s100706662.

[6] D. Decasper, M. Waldvogel, Z. Dittia, H. Adiseshu, G. Parulkar, B. Plattner, Crossbow: a toolkit for integrated services over cell switched IPv6, IEEE ATM '97 Workshop Proceedings (Cat. No.97TH8316). (n.d.). doi:10.1109/atm.1997.624698.

[7] S. Soro, W. Heinzelman, On the coverage problem in video-based wireless sensor networks, 2Nd International Conference On Broadband Networks, 2005. (n.d.). doi:10.1109/icbn.2005.1589704.

[8] N. Tezcan, W. Wang, Self-Orienting Wireless Multimedia Sensor Networks for Maximizing Multimedia Coverage, 2008 IEEE International Conference On Communications. (2008). doi:10.1109/icc.2008.421.

[9] J. Adriaens, S. Megerian, M. Potkonjak, Optimal Worst-Case Coverage of Directional Field-of-View Sensor Networks, 2006 3Rd Annual IEEE Communications Society On Sensor And Ad Hoc Communications And Networks. (2006). doi:10.1109/sahcn.2006.288438.

[10] O. Chipara, Z. He, G. Xing, Q. Chen, X. Wang, C. Lu et al., Real-time Power-Aware Routing in Sensor Networks, 200614Th IEEE International Workshop On Quality Of Service. (2006). doi:10.1109/iwqos.2006.250454.

[11] E. Felemban, C. G. Lee, E. Ekici, MMSPEED: multipath Multi-SPEED protocol for QoS guarantee of reliability and. Timeliness in wireless sensor networks, IEEE Transactions On Mobile Computing. 5 (2006) 738-754. doi:10.1109/tmc.2006.79.

[12] M. Razzaque, M. Alam, M. M. Rashid, C. Hong, Multi-Constrained QoS Geographic Routing for Heterogeneous Traffic in Sensor Networks, 2008 5Th IEEE Consumer Communications And Networking Conference. (2008). doi:10.1109/ccnc08.2007.42.

[13] B. Nefzi, R. Schott, Y. Song, G. Staples, E. Tsiontsiou, An Operator Calculus Approach for Multi-constrained Routing in Wireless Sensor Networks, Proceedings Of The 16Th ACM International Symposium On Mobile Ad Hoc Networking And Computing - Mobihoc '15. (2015). doi:10.1145/2746285.2746301.

[14] H. Shen, G. Bai, Z. Tang, L. Zhao, QMOR: QoS-Aware Multi-sink Opportunistic Routing for Wireless Multimedia Sensor Networks, Wireless Personal Communications. 75 (2013) 1307-1330. doi:10.1007/s11277-013-1425-0.

[15] P. Boluk, S. Baydere, A. Harmanci, Perceptual quality-based image communication service framework for wireless sensor networks, Wireless Communications And Mobile Computing. 14 (2011) 1-18. doi:10.1002/wcm.1218.

[16] M. Osborne, An introduction to game theory, Oxford University Press, New York, 2012.

[17] Z. Ke, L. Li, Q. Sun, N. Chen, Ant-Like Game Routing Algorithm for Wireless Multimedia Sensor Networks, 2008 4Th International Conference On Wireless Communications, Networking And Mobile Computing. (2008). doi:10.1109/wicom.2008.843.

[18] P. Boluk, S. Baydere, A. Harmanci, Perceptual quality-based image communication service framework for wireless sensor networks, Wireless Communications And Mobile Computing. 14 (2011) 1-18. doi:10.1002/wcm.1218.

[19] M. Alaei, J. Barcelo-Ordinas, A Method for Clustering and Cooperation in Wireless Multimedia Sensor Networks, Sensors. 10 (2010) 3145-3169. doi:10.3390/s100403145.

[20] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, An application-specific protocol architecture for wireless microsensor networks, IEEE Transactions On Wireless Communications. 1 (2002) 660-670. doi:10.1109/twc.2002.804190.

[21] Y. Sun, H. Ma, L. Liu, Y. Zheng, ASAR: An ant-based service-aware routing algorithm for multimedia sensor networks, Frontiers Of Electrical And Electronic Engineering In China. 3 (2008) 25-33. doi:10.1007/s11460-008-0013-7.

[22] M. Hamid, M. Alam, C. Hong, Design of a QoS-Aware Routing Mechanism for Wireless Multimedia Sensor Networks, IEEE GLOBECOM 2008 - 2008 IEEE Global Telecommunications Conference. (2008). doi:10.1109/glocom.2008.ecp.159.

[23] L. Liu, X. Zhang, H. Ma, Dynamic Node Collaboration for Mobile Target Tracking in Wireless Camera Sensor Networks, IEEE INFOCOM 2009 - The 28Th Conference On Computer Communications. (2009). doi:10.1109/infcom.2009.5062032.

[24] M. Hamid, M. Alam, C. Hong, Design of a QoS-Aware Routing Mechanism for Wireless Multimedia Sensor Networks, IEEE GLOBECOM 2008 - 2008 IEEE Global Telecommunications Conference. (2008). doi:10.1109/glocom.2008.ecp.159.

[25] Z. Ke, L. Li, N. Chen, A Crossover Game Routing Algorithm for Wireless Multimedia Sensor Networks, 2008 Ninth ACIS International Conference On Software Engineering, Artificial Intelligence, Networking, And Parallel/Distributed Computing. (2008). doi:10.1109/snpd.2008.15.

[26] H. Haiping, W. Ruchuan, Clustered-Control Algorithm for Wireless Multimedia Sensor Network Communications, 2010 International Conference On Communications And Mobile Computing. (2010). doi:10.1109/cmc.2010.130.

[27] S. Medjiah, T. Ahmed, F. Krief, GEAMS: A Geographic Energy-Aware Multipath Stream-based routing protocol for WMSNs, 2009 Global Information Infrastructure Symposium. (2009). doi:10.1109/giis.2009.5307078.

[28] M. Gerla, K. Xu, Multimedia streaming in large-scale sensor networks with mobile swarms, ACM SIGMOD Record. 32 (2003) 72. doi:10.1145/959060.959073.

[29] M. Maimour, Maximally radio-disjoint multipath routing for wireless multimedia sensor networks, Proceedings Of The 4Th ACM Workshop On Wireless Multimedia Networking And Performance Modeling - Wmunep '08. (2008). doi:10.1145/1454573.1454579.

[30] Shuang Li, R. Neelisetti, Cong Liu, A. Lim, Delay-constrained high throughput protocol for multi-path transmission over wireless multimedia sensor networks, 2008 International Symposium On A World Of Wireless, Mobile And Multimedia Networks. (2008). doi:10.1109/wowmom.2008.4594815.

[31] L. Shu, Y. Zhang, L. Yang, Y. Wang, M. Hauswirth, Geographic Routing in Wireless Multimedia Sensor Networks, 2008 Second International Conference On Future Generation Communication And Networking. (2008). doi:10.1109/fgcn.2008.17.

[32] Y. Lan, W. Wenjing, G. Fuxiang, A real-time and energy aware QoS routing protocol for Multimedia Wireless Sensor Networks, 2008 7Th World Congress On Intelligent Control And Automation. (2008). doi:10.1109/wcica.2008.4594494.

[33] S. Medjiah, T. Ahmed, A. Asgari, Streaming multimedia over WMSNs: an online multipath routing protocol, International Journal Of Sensor Networks. 11 (2012) 10. doi:10.1504/ijsnet.2012.045036.

[34] X. Cao, R. Wang, H. Huang, L. Sun, F. Xiao, Multi-Path Routing Algorithm for Video Stream in Wireless Multimedia Sensor Networks, Journal Of Software. 23 (2012) 108-121. doi:10.3724/sp.j.1001.2012.04070.

[35] Z. Hamid, F. Hussain, QoS in Wireless Multimedia Sensor Networks: A Layered and Cross-Layered Approach, Wireless Personal Communications. 75 (2013) 729-757. doi:10.1007/s11277-013-1389-0.

[36] A. Sheikh, E. Felemban, and S. Basalamah, "Priority-Based Routing Framework for Multimedia Delivery in Surveillance Networks," 6th Int'l. Conf. Advances in Multimedia, 2014, pp. 1–9.

[37] M. Tahir, R. Farrell, A cross-layer framework for optimal delay-margin, network lifetime and utility tradeoff in wireless visual sensor networks, Ad Hoc Networks. 11 (2013) 701-711. doi:10.1016/j.adhoc.2011.09.011.

[38] D. Kandris, M. Tsagkaropoulos, I. Politis, A. Tzes, S. Kotsopoulos, Energy efficient and perceived QoS aware video routing over Wireless Multimedia Sensor Networks, Ad Hoc Networks. 9 (2011) 591-607. doi:10.1016/j.adhoc.2010.09.001.

[39] R. Dai, P. Wang, I. Akyildiz, Correlation-Aware QoS Routing With Differential Coding for Wireless Video Sensor Networks, IEEE Transactions On Multimedia. 14 (2012) 1469-1479. doi:10.1109/tmm.2012.2194992.

[40] L. Cobo, A. Quintero, S. Pierre, Ant-based routing for wireless multimedia sensor networks using multiple QoS metrics, Computer Networks. 54 (2010) 2991-3010. doi:10.1016/j.comnet.2010.05.014.

[41] T. Houngbadji, S. Pierre, QoSNET: An integrated QoS network for routing protocols in large scale wireless sensor networks, Computer Communications. 33 (2010) 1334-1342. doi:10.1016/j.comcom.2010.03.017.

[42] K. Lin, J. Rodrigues, H. Ge, N. Xiong, X. Liang, Energy Efficiency QoS Assurance Routing in Wireless Multimedia Sensor Networks, IEEE Systems Journal. 5 (2011) 495-505. doi:10.1109/jsyst.2011.2165599.

[43] I. Almalkawi, M. Guerrero Zapata, J. Al-Karaki, A Cross-Layer-Based Clustered Multipath Routing with QoS-Aware Scheduling for Wireless Multimedia Sensor Networks, International Journal Of Distributed Sensor Networks. 8 (2012) 392515. doi:10.1155/2012/392515.

[44] E. Cañete, M. Díaz, L. Llopis, B. Rubio, HERO: A hierarchical, efficient and reliable routing protocol for wireless sensor and actor networks, Computer Communications. 35 (2012) 1392-1409. doi:10.1016/j.comcom.2012.04.003.

[45] K. Sohrabi, J. Gao, V. Ailawadhi, G. Pottie, Protocols for self-organization of a wireless sensor network, IEEE Personal Communications. 7 (2000) 16-27. doi:10.1109/98.878532.

[46] C. Lu, B. Blum, T. Abdelzaher, J. Stankovic, Tian He, RAP: a real-time communication architecture for large-scale wireless sensor networks, Proceedings. Eighth IEEE Real-Time And Embedded Technology And Applications Symposium. (n.d.). doi:10.1109/rttas.2002.1137381.

[47] J. Kim, H. Seo, J. Kwak, Routing Protocol for Heterogeneous Hierarchical Wireless Multimedia Sensor Networks, Wireless Personal Communications. 60 (2011) 559-569. doi:10.1007/s11277-011-0309-4.

[48] M. Hasan, F. Al-Turjman, H. Al-Rizzo, Optimized Multi-Constrained Quality-of-Service Multipath Routing Approach for Multimedia Sensor Networks, IEEE Sensors Journal. 17 (2017) 2298-2309. doi:10.1109/jsen.2017.2665499.

[49] L. Han, S. Sun, B. Joo, X. Jin, S. Han, QoS-Aware Routing Mechanism in OpenFlow-Enabled Wireless Multimedia Sensor Networks, International Journal Of Distributed Sensor Networks. 12 (2016) 9378120. doi:10.1177/155014779378120.

[50] N. Magaia, N. Horta, R. Neves, P. Pereira, M. Correia, A multi-objective routing algorithm for Wireless Multimedia Sensor Networks, Applied Soft Computing. 30 (2015) 104-112. doi:10.1016/j.asoc.2015.01.052.

[51] K. Akkaya, M. Younis, A survey on routing protocols for wireless sensor networks, Ad Hoc Networks. 3 (2005) 325-349. doi:10.1016/j.adhoc.2003.09.010.

[52] H. Shin, S. Moh, I. Chung, Clustering with One-Time Setup for Reduced Energy Consumption and Prolonged Lifetime in Wireless Sensor Networks, International Journal Of Distributed Sensor Networks. 9 (2013) 301869. doi:10.1155/2013/301869.

[53] K. Singh, S. Moh, Routing protocols in cognitive radio ad hoc networks: A comprehensive review, Journal Of Network And Computer Applications. 72 (2016) 28-37. doi:10.1016/j.jnca.2016.07.006.

ACKNOWLEDGEMENT

First, I would love to thank my advisor, Prof. Sangman Moh, for his wonderful guidelines and care during the entire program. His invaluable advices and continuous encouragement have dragged the best out of me. Without his supports and guidelines, I could not have finished this research.

Besides my advisor, I would love to thank the committee members, Prof. Ilyong Chung and Prof. Seokjoo Shin, for their constructive comments and valuable advices to increase the quality of the research.

Also, I am grateful to the department of computer engineering, Chosun University, for giving me such a wonderful environment of cooperation and learning. I am also thankful to all of my lab mates for being so helpful and generous.

I cannot help thanking my family members. Even from a distance so far, they have been always by my side to give me inspiration. I would like to especially thank Md Junayed Hasan and Ijaz Ahmed for their continuous help in my works and life. I would also like to thank Anna Marie, Lynne Yang, Madeline Miller, 성일 범, and 이금용 for inspring and motivating me to give the best of mine to accomplish my research.