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Energy Efficient Routing Protocols for Mobile Robots: A Review

Smt. Thilagavathy, R[1*], Dr. Sumithra Devi, K. A[2], Saagar, M. P[3]

[1]Research Scholar, Dept. of ECE, Dayanand Sagar Academy of Technology and Management, Bengaluru, India
[2]Dean Academics & HOD, Department of ISE, DSATM, Bengaluru, India
[3]Mechanical Department, The National Institute of Engineering, Mysuru, India

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***Corresponding author:** Smt. Thilagavathy, R
Research Scholar, Dept. of ECE, Dayanand Sagar Academy of Technology and Management, Bengaluru, India

Abstract

Many vital applications benefit from mobile multi-robot teams, including search and rescue, environmental monitoring, military, unmanned space exploration, hazard detection and analysis. Communication between robots is important for group coordination and information sharing in mobile multi-robot teams. Because many mobile robot applications involve scenarios where communication infrastructure is destroyed or unavailable, mobile robot teams must regularly connect with one another through ADHOC networking. In such situations, low over-head and energy efficient routing systems for sending information are essential. The most difficult task is to provide a unified foundation for robot communication. The framework of Mobile Robots is described in this paper, as well as a review and analysis of several research papers on Energy Efficient Routing in Robotic Wireless sensor networks (RWSN).

Keywords: Multi-Robot, Energy-Efficient, Communication, Coordination, Routing_ Protocols, Robotic Wireless-Sensor-Network.

1. INTRODUCTION

Swarms of heterogeneous robots, either as unmanned ground vehicle (UGV) or as unmanned aerial vehicle (UAV), are increasingly being used in complex applications such as search and rescue, mapping of an unknown space, Monitoring, shipping, parcel delivery and surveillance. The coordination of the robots (ground and/or aerial) is critical in the majority of such complicated applications [1]. As the public's interest in robots grows, so does the relevance of robot communications, which drives the creation of structures that simplify robotic communication protocols. This discussion aims to provide some insights into the evolution of robot communication protocols.

In many instances, robot teams have benefits over solo robots. It's sometimes more cost-effective to develop a series of smaller, simpler devices that are each less capable than a larger robot, but when combined, provide far greater capacity. A team of robots can sense and affect more domains than a single robot. Furthermore, redundancy can improve the reliability of a group of collaborating robots' performance. The concept of cooperative robots is enhanced by modular system design, which allows for a clear division of labour among robots, each of which is an expert at one type of work, such as painting or welding. Without communications, it would be impossible to coordinate a team of robots in a stochastic environment, and any communications strategy but the most basic will complicate robotic system analysis and design significantly. However, by arranging the interactions using appropriate communications protocols, these problems can be considerably reduced. This study looks at a variety of elements of robot communication from the standpoint of computer networking protocols, which has influenced the approach significantly.

1.1 The Problem

Communication is the process of sending and receiving data between robots in order to complete jobs. The communication network also refers to the distance and bandwidth across which robots may communicate, whereas the communication method is determined by the configuration/pattern. Coordination among robots is the most important aspect in completing any task in an application. Communication between robots is the only way to achieve coordination. Navigation and communication consume the majority of a robot's energy. The transmission range and battery capacity limit the robots' ability to communicate [2]. Communication consumes around 51% of total energy. Providing a standard structure for robot navigation and communication is the most demanding challenge. The fundamental concept is to use the least amount of energy for communication so that the most amount of energy can be used for navigation. Here are some of the most essential energy-efficient routing techniques.

1.1.1 Unicast-and Multicast-Routing Protocols

Communication amongst mobile multirobot is necessary and perhaps important in the majority of applications. Applications like search and rescue may have damaged or non-existent communication infrastructure. Mobile robots must build an ad hoc network, where each node serves as a forwarding node, in order to exchange messages. So, in order to send messages between mobile multirobot or from multirobot to a human operator, effective routing protocols that can operate without centralized management and endure dynamical topology changes are required. There are two primary types of messaging needs for mobile robot applications: (1) Several applications require unicast messages to be sent from one mobile robot to another robot for conveying data and photos, requesting assistance, and so on. (2) Sending multicast signals from a single user or a single mobile robot to a group of receiving robots is a common way to establish coordination and control.

Unicast messaging is effective for communication that requires coordination. Coordination-oriented communication has been extensively investigated in the literature and is defined as transmission linked to the-collaboration and the command the robot-teams. Particularly, the application of networking for multirobot control was examined in [3]. Communication has-been demonstrated to boost performance in specific tasks [4].

Group communication protocols must be able to function without centralized supervision and manage dynamic topology changes due to the mobility of mobile robots. The most important primitive for group communication is multicasting, which is employed in applications that need close team cooperation. (e.g., Search and rescue teams). Multicast is extremely useful when speech signal, video signal, images, and other sorts of data must be shared across team members. Multicast allows you to send the same data to several recipients in an effective manner. When compared to numerous unicasts, multicast reduces connection bandwidth utilization, transmitter & router processing, and delivery latency. Because it reduces the number of broadcasts needed to communicate with a collection of robotic recipients, multicast is helpful in lowering group communication's energy consumption in a mobile multirobot team network [5].

To show how multicast can be used as a primitive for the communication in group of mobile robot networks, consider the following three scenarios: One robot in a network of mobile robots may first use multicast communication to speak with a number of other robots. For Instance, only a subset of nodes in a huge Mobile Robot team may be equipped with Global Positioning System (GPS) or other geolocation devices. These nodes might be configured in a multicast group to communicate often about their locations and work as waypoints and navigation assistance for other robots who are ignorant of their location. Robots having video cameras, together with other robots in the "cam" group, for instance, may create a global map. A robot can find other robots with a certain capacity or resource by using multicast groups created based on capabilities. Finally, to assist effective collaboration and coordination, all robots with similar skills might join a multicast group.

Second, multicast communications from human operators may be required to efficiently control a group of mobile robots. The human operator might, for instance, choose only to communicate with and manage a set of robots that are all equipped with a certain chemical sensor. To control the robots, the human operator might put them in a high availability group if their remaining energy was above a specified threshold. Multicast groups can be used to divide a robot team into smaller groups for easier management and control. Depending on the context and application, these sub teams can be grouped together, separated, or organized hierarchically. A mobile robot can transmit multicast messages to a number of controllers or sinks, much like a sensor network. For instance, a platoon commander group outside the minefield may require communication from a set of demining robots on their findings. As a result, multicast communication can be utilized for data distribution. For use in mobile ad hoc networks, numerous unicast and multicast protocols have been developed. (e.g. DSR [6], AODV [7], MAODV [8], ODMRP [9], MCEDAR [10], DDM [11]).

Mobile_Robot_Source_Routing_(MRSR), a multi-hop unicast routing system for MANETs that uses source routing rather than hop-by-hop routing, is based on Dynamic Source Routing (DSR) [6]. The MRSR includes all the 3 phases of route development: discovery, building, and maintenance. During the route discovery phase, each robot encapsulates its mobility data into the route reply packet in addition with the route reply message path. During route building, MRSR stores the network's topological data in a graph cache. The DSR maintenance process is similar to the route maintenance phase.

Mobile Robot Distance Vector (MRDV), a unicast routing protocol that draws inspiration from the well-known Ad-hoc On-demand Distance Vector (AODV) [7]. MRDV and MRSR/DSR both exhibit on-demand behaviour, and Destination Sequenced Distance Vector (DSDV) [12], use sequence numbers based on destinations and hop-by-hop routing.

Mobile_Robot_Mesh_Multicast_(MRMM) is developed using the multicast On Demand Multicast Routing Protocol (ODMRP), which was created for MANETs. The MRMM protocol is a modification of the ODMRP protocol that adds capability for mobile robots. Like ODMRP, MRMM makes use of a mesh to provide redundancy, more efficient delivery, and to handle the challenges associated with maintaining trees in mobile networks. MRMM, like ODMRP, is divided into two key phases: (1) Mesh construction and maintenance: By incorporating some of the mobile robots in the network, a mesh is formed. The mesh is a chain structure in which all group members are mesh members. In order to prevent disconnections and provide redundancy, a predetermined group of foreigners are engaged to send the packets. (2) Data_delivery: Mesh robots distribute data_packets so that each group member can simultaneously receive them.

1.1.2 Routing protocols not based on Swarm Intelligence principles

Clustering [13] is one of the most common wireless network protocols. A cluster head and other numerous sensor nodes are known as cluster members, and clustering organizes several nodes into clusters, each of which has a cluster head. Only the cluster heads communicate with the base station or sink; Each cluster head receives the data from its corresponding cluster members. By doing this, nodes that are far from the nearby base station can conserve electricity. As a result, clustering is acknowledged as a low-energy communication technology. There are two types of cluster head selection algorithms in traditional cluster design. One is homogeneous approaches, in which all nodes have the same energy at the beginning. The other is heterogeneous approaches, which use nodes with varying beginning energies. Once deployed, all nodes in these cluster-head selection techniques are considered to remain stationary.

In a WSN, network energy efficiency is a key consideration. When networks grow, more data is collected as well, which requires a lot of energy and leads nodes to fail early. In order to reduce the amount of power needed for data sampling and acquisition and hence increase the network's lifetime, a number of energy-efficient protocols have been created. These are a few routing protocols that are energy-efficient:

1. **Low-Energy Adaptive Clustering Hierarchy** (**LEACH**)

Most nodes communicate to cluster heads (CH) using this form of hierarchical protocol [14, 15]. There are two phases_to it: (i). The Setup Phase : This stage involves organizing the clusters and choosing the Cluster Head (CH). It is CH's duty to collect, organize, and send data to the base station (Sink) [16]. (ii). The Study State Phase: The cluster head and nodes are configured in the earlier step, however the second stage of "LEACH" involves data transfer to the base station (Sink). It lasts a bit too long than the preceding stage. To cut down on overhead, this stage has been lengthened. The cluster head establishes communication with each network node and receives data from them. The cluster head then creates a timeline for the data transfer from each node to the base station [15, 16].

2. **Power-Efficient Gathering in Sensor Information Systems (PEGASIS**)

It replaces the "LEACH" with a "chain-based protocol." Each node in "PEGASIS" only connects with a close neighbour to direct and acquire information. It communicates with the BS alternately, reducing the round's energy consumption [17]. A chain of nodes that can be finished by algorithm and sensor nodes is formed by their connections. Instead, the BS may form this chain and send it to all sensor nodes [18]. All nodes should have universal system knowledge, and the chain should be built using a greedy algorithm. The chain will therefore be constructed from the farthest node to the nearest node. When a node dies, the chain is similarly regenerated to prevent the dead node [19].

3. **Threshold sensitive Energy Efficient sensor Network protocol** (**TEEN**)

The hierarchical TEEN protocol was developed for cases involving abrupt changes in measurable parameters, including temperature. TEEN [20] was the very first reactive network protocol. With a hard threshold, transmissions are restricted such that nodes only exchange information when a detected attribute is within a predetermined range. By removing any transmissions that might occur once the sensed attribute is only slightly or never changed, soft threshold lowers transmissions. TEEN responds quickly, is energy-efficient, and is a good choice for situations where speed is of the essence. The user can also modify the application's power requirements and level of precision [21].

4. **Adaptive Threshold sensitive Energy Efficient Sensor Network (APTEEN)**

The "APTEEN" is a development of the "TEEN" with the goal of collecting temporal information and responding to emergency conditions. The Cluster head communicates the characteristics, parameters, and transmission plan to each node as quickly as the BS establishes the clusters [20]. Later, the Cluster head accumulates data in order to save power. The key benefit of "APTEEN" over "TEEN" is the reduction in power consumption at the nodes. The main disadvantages of APTEEN are its intricacy and the prolonged delay durations it produces.

5. **Directed Diffusion**

WSNs use directed diffusion, a data-centric routing technology, to collect and disseminate information [23]. When data must flow from the sink to the sensors or when the sink needs a specific type of data from the sensors, it was developed in response. Its main goal is to drastically cut energy usage and thereby increase the network's lifespan. To achieve this purpose, it must keep the nodes' interactions within a limited context via exchanging messages. A confined interaction distinguishes this protocol, allowing for multipath delivery. The nodes' capacity to respond to inquiries from the base station and this special feature result in substantial energy savings [14, 23].

6. Energy-Efficient_Sensor_Routing_ (EESR)

EESR is a flat routing method [24] for wireless sensor networks that aims to improve power consumption, data latency, and scalability. The key components are the Gateway, Base Station, Manager Nodes, and Sensor Nodes [25, 26]. Gateways transfer messages from Manager Nodes in order to create new pathways for the Ground Station, having greater requirements than typical sensor nodes. It transmits and collects messages to communicate with Gateway. It also transmits and receives information and requests from the sensor nodes. Manager Nodes and Sensor Nodes gather information from their vicinity and deliver it in a single hop to the Base Station [24].

The following table 1 [33], presenting more detailed comparison of majority of energy efficient non SI based protocols.

Table 1: Comparison of non-SI based Routing Protocols

	Class	Energy Efficient	Lifetime	Scalability	Through put
LEACH [16]	HIERARCHIAL	HIGH	EXCELLENT	HIGH	VERY HIGH
PEGASIS [27]	HIERARCHIAL	HIGH	EXCELLENT	GOOD	VERY HIGH
TEEN [21]	HIERARCHIAL	LIMITED	GOOD	GOOD	SATISFACTORY
APTEEN [22]	HYBRID	LIMITED	EXCELLENT	GOOD	HIGH
DIRECTED DIFFUSION [23]	FLAT	HIGH	GOOD	RESTRICTED	SATISFACTORY
EESR [24]	FLAT	HIGH	EXCELLENT	HIGH	HIGH
SPIN [54]	FLAT	LIMITED	GOOD	LIMITED	SATISFACTORY
USEP [48]	FLAT	MAXIMUM	EXCELLENT	GOOD	HIGH

1.1.3 Swarm Intelligence based Routing Protocols

Natural biological swarm intelligence offers several powerful qualities that are desirable in many engineering systems, such as network routing. Furthermore, analytically comprehending, expanding the principles of design and behaviour shown by intelligent biological swarms may result in new paradigms for developing autonomous and scalable systems. Due to the growing scale, rapidly changing topology, mobility, and complexity of communication networks, administration is becoming increasingly difficult. A new class of algorithms is now being developed that is inspired by swarm intelligence and has the ability to tackle many of the challenges that current Wireless Sensor Networks require. These algorithms depend on numerous actors communicating with each other simultaneously. This paper presents a review of such algorithms and their performance. There are three types of SI-based routing protocols: ant-based, bee-based, and slim-based algorithms. The most important protocols are as follows:-

1. Ant Colony Optimization based routing protocols:

The ideas underlying ant foraging behaviour served as the foundation for the Ant Colony Optimization (ACO) related routing technique [28], which allows an ant colony to complete complicated tasks like nest construction and foraging.

2. Bee colony based routing protocols:

The foraging activities of honeybees inspired these methods. Routing in computer networks resembles honeybee behaviour in various ways [29]. Honeybees, in particular, feature WSN-related mechanisms such as the division of tasks and self-organization. Many WSN routing protocols exists that are based on the behaviour of bees.

3. Slime mold based routing protocols:

Heterotrophic organisms are referred to as slime moulds. Wireless sensor networks and swarms of monocellular organisms share a number of striking parallels. As was already noted, one way to think of a wireless sensor network is as a "Swarm" of sensor nodes. The above mentioned are basic nodes that can respond on their own, with little capacity and resources. As a result, they can complete simple activities [30]. Nonetheless, certain works have been created based on slime mould behaviour.

The following table 2 [30-32], presenting more detailed comparison of majority of SI based_ protocols.

2. EXISTING RESEARCH METHODOLOGIES

One of the most difficult and crucial challenges in Multirobot Systems (MRS) is effective robot communication. Communication quality in the exploration domain suffers as a result of the distance between peer robots or base stations (BS), barriers, and a variety of other topographical factors. A high-bandwidth wireless network enables for efficient communication. Communication assistance is a significant energy investment since additional payload quickly drains the battery.

Battery life and robot identification are indicated by a robot's individual state. Task data denotes sensor-provided task-specific data, and environmental state denotes harmful environmental oscillations that can block reliable robot communication. The most notable work on energy efficient routing protocols is shown in Table 3.

3. RESEARCH AND DISCUSSION

This section focuses on the research gap in mobile robot routing protocol efficiency. After evaluating some papers, the following research gaps were discovered, and a summary of research works is shown in Table 3.

Table 3 briefly summarises the available energy-efficient routing strategies for mobile robot communication. It has been observed that the majority of present research focuses on traditional routing protocols rather than swarm intelligence-based routing protocols.

Table 2: Comparison of SI based Routing Protocols

Routing_ Protocols	Energy_ Efficiency	Network_ Lifetime	Scalability	Swarm_ Technique	Simulator
Optimal Sink Location [35]	MODERATE	LOW	LOW	PSO	MATLAB
IC-ACO	LOW	LOW	LOW	ACO	MATLAB
DTP-ACO	HIGH	HIGH	HIGH	ACO	MATLAB
Mobile Sink [36]	LOW	LOW	LOW	PSO	NS2
ACO_TCAT	MODERATE	MODERATE	LOW	ACO	VISUAL_C++ 6.0
ACO_GREEDY	HIGH	HIGH	HIGH	ACO	VISUAL_C++ 6.0
PEEBR	HIGH	HIGH	LOW	BCO	VISUAL_C++ 6.0
BEE SENSOR	VERY_HIGH	HIGH	LOW	BCO	NS2
Energy_Aware Clustering [34]	VERY HIGH	HIGH	LOW	PSO	NS2
Parallel Ant Colony Optimization	LOW	LOW	LOW	ACO	JAVA
ANT_CHAIN	HIGH	VERY_HIGH	LOW	ACO	NS2
EEABR	VERY HIGH	HIGH	LOW	ACO	NS2
ACLR	VERY HIGH	LOW	LOW	ACO	Opnet
QAAB	VERY HIGH	HIGH	LOW	ACO	Glomosim 2.0
Ant-0, Ant-1 & Ant-2, E and D ants	VERY HIGH	LOW	LOW	ACO	Opnet
SC-Ant	VERY HIGH	LOW	LOW	ACO	The_Pursuer_Evader Game (Peg)
FF-Ant & FP-Ant	LOW	LOW	LOW	ACO	The Pursuer Evader Game (Peg)
MADFT	HIGH	LOW	LOW	ACO	C++

Given all of the protocols covered in this paper, it is clear that there has been relatively little research on security and QoS parameters, and the majority of the protocols presume that the sink node is immobile, which poses a research obstacle. When conducting research, each node in the topology should be viewed as dynamic and movable, with a constantly changing environment. With a focus on each node's energy efficiency, the new routing protocols needed for Robotic Wireless Sensor Network (RWSN) should be able to withstand mobility overhead and random topology changes while retaining the best possible paths.

Table 3: Survey of existing efficient routing protocol for MRS

Sl. No	Routing Protocol	Author	Outcomes
1 2 3	Unicast & Multicast routing protocols	Saumitra M. Das *et al.*, [37] Y. Charlie Hu *et al.*, [38] George Lee *et al.*, [39]	• Low Control Overhead • Forwarding Efficiency is More • Performance of packet delivery is unaffected. • Reduces the bandwidth usage • Lowers the energy required for group communication in the network of mobile robots.

4 5 6 7 8 9 10 11 12 13 14	Non-SI based routing protocol	Donghoon Lee *et al.*, [40] Md. Enamul Haque *et al.*, [41] Omer Melih Gul *et al.*, [42] Yan Shen *et al.*, [43] Pardeep Kaur *et al.*, [33] Debraj Basu *et al.*, [44] Md. Elhoseny *et al.*, [45] Olayinka O. Ogundile *et al.*, [46] Sarika Yadav *et al.*, [47] Surendra Verma *et al.*, [48] Adamu Murtala Zungeru *et al.*, [49]	• Improves the network life time • Energy minimization • Usage of mobile sensors • Dynamic recharging • Hazardous region exploration • Even mobility is high, data loss is less • Improve battery life • Maximum energy efficacy • Reducing the amount of data transfers • Increasing the total number of active nodes over time • Efficiently distributing energy among the sensor nodes in the WSN
15 16 17 18 19 20 21	SI based routing protocol	Priyanka chhillar [32] Sungju Huh *et al.*, [50] Muhammad Saleem *et al.*, [51] Mabrouka Abuhmida *et al.*, [31] Adamu Murtala Zungeru *et al.*, [52] Sandra Sendra *et al.*, [53] Kiran Jot Singh *et al.*, [2]	• Energy consumption is less in the network. • Significant power saving by reducing data traffic up to 82%. • Maximum energy efficiency • Better Performance, when the network is dynamic • Iimproves the network life time • Maximum energy efficiency

4. CONCLUSION

Designing and implementing a packet delivery routing system for mobile robots that is energy-efficient, durable, scalable, and effective is a demanding task. Various options for multi-robot communication were explored in this paper, taking into account the communication constraints that exist when it comes to robot-to-robot communication. This study discusses the problem of robots providing information to the BS at predetermined intervals while maintaining effective communication and extending the network's life.

We have offered a full and comprehensive evaluation of Routing Protocols for Mobile Robots in this paper. The majority of existing techniques are centered on traditional routing protocols, indicating that there is little innovation in this domain. The energy-efficient routing algorithms in wireless sensor networks were investigated in this paper. Following that, the key categories were presented, and relevant parameters from matching protocols were compared. Even if these protocols are energy-efficient, factors like Quality of service (QoS) must be taken into consideration to ensure that the most energy-efficient form of information transfer is selected, as well as to guarantee a guaranteed data transfer rate or delay.

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