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ORIGINAL ARTICLE

Location aware event driven multipath routing in Wireless Sensor Networks: Agent based approach

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Abstract Wireless Sensor Networks (WSNs) demand reliable and energy efficient paths for critical information delivery to sink node from an event occurrence node. Multipath routing facilitates reliable data delivery in case of critical information. This paper proposes an event triggered multipath routing in WSNs by employing a set of static and mobile agents. Every sensor node is assumed to know the location information of the sink node and itself. The proposed scheme works as follows: (1) Event node computes the arbitrary midpoint between an event node and the sink node by using location information. (2) Event node establishes a shortest path from itself to the sink node through the reference axis by using a mobile agent with the help of location information; the mobile agent collects the connectivity information and other parameters of all the nodes on the way and provides the information to the sink node. (3) Event node finds the arbitrary location of the special (middle) intermediate nodes (above/below reference axis) by using the midpoint location information given in step 1. (4) Mobile agent clones from the event node and the clones carry the event type and discover the path passing through special intermediate nodes; the path above/below reference axis looks like an arc. While migrating from one sensor node to another along the traversed path, each mobile agent gathers the node information (such as node id, location information, residual energy, available bandwidth, and neighbors connectivity) and delivers to the sink node. (5) The sink node constructs a partial topology, connecting event and sink node by using the connectivity information delivered by the mobile agents. Using the partial topology information, sink node finds the multipath and path weight factor by using link efficiency, energy ratio, and hop distance. (6) The sink

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node selects the number of paths among the available paths based upon the criticalness of an event, and (7) if the event is non-critical, then single path with highest path weight factor is selected, else multiple paths are selected for the reliable communication. The performance of the proposed scheme is tested in terms of performance parameters such as packet delivery ratio, energy consumption, latency, and overhead.

1. Introduction

Due to recent technological advances, manufacturing of tiny and low cost sensors has become technically and economically feasible. Wireless Sensor Networks (WSNs) consist of sensor nodes with sensing, computation, and wireless communication capabilities [1–5]. Sensor nodes have the ability to communicate either among each other or directly to an external base station (BS) called as sink. The deployments of more number of sensors allow sensing over larger geographical regions with greater accuracy. The sensors can monitor diversified entities such as temperature, pressure, humidity, salinity, metallic objects, and mobility. The monitoring competence can be effectively used in applications like military, fire detection, earthquake monitoring, disaster management, habitat monitoring, and environmental monitoring, which require unattended operations.

In traditional WSNs, sensor nodes periodically gather data and report to the sink node by using the multihop communication. During data gathering, sensors have the ability to perform in-network aggregation of data packets enroute to the sink node. Using conventional methods of data gathering and processing in WSNs may lead to some of the limitations like excess energy consumption, redundant data transmission, increased latency, and bandwidth overheads. The critical issue in a WSN is the network lifetime which is mainly dependent on the energy of sensor nodes [6].

Recently, multipath routing approach is widely used in WSNs to improve network performance by efficiently utilizing the network resources as well to improve the reliability of information delivery. Routing techniques are classified based on the network structure into three categories: flat, hierarchical, and location based routing protocols. Furthermore, these protocols are classified into multipath-based, query-based, negotiation-based, or QoS-based routing techniques based on the protocol operation. Some of the challenges in routing for WSNs are data reporting, node/link heterogeneity, fault tolerance, scalability, network dynamics, coverage, connectivity, etc. [7–9].

In WSN, the communication cost is often several orders of magnitude higher than the computation cost. During the routing phase, the sensed data, query, and control messages travel from a node to another to reach their destination. This consumes a considerable amount of sensors energy. Therefore, many routing protocols are presented for saving the sensor node's energy and prolong their lifetime. Due to restricted communication range and high density of sensor nodes, packet forwarding is done through multihop data transmission.

Multipath routing between a given (sink, source) pair based on Bezier curves that helps in load balancing among the relay nodes for the purpose of prolonging the WSNs lifetime is presented in [10]. Selecting the Bezier curve control points is one of the crucial tasks between the source node and the sink node. The construction of the routes based on Bezier curves can be done locally with a small overhead in terms of transmitted parameters; each relay node can decide who should be the next hop along that particular route toward the sink. The major overheads in using Bezier curve for multipath routing is entire trajectory points are to be encoded with the every transmitted packet from source to sink node.

1.1. Related works

Some of the related works are as follows: A low interference energy efficient multipath routing protocol (LIEMRO) to improve the QoS requirements of event driven applications is presented in [11]. An on-demand multipath routing protocol based on parametric probability for WSNs presented in [12] discusses balanced energy consumption among sensor nodes and maximizes the network lifetime. The different data generated at the same sensor node may pick up different transmission paths according to a probability that depends on various parameters, such as the hop distance from intermediate node to sink and residual energy of intermediate node. Furthermore, balance among multipath based on the energy usage at neighbors is considered in selection of the path.

Secure multipath routing algorithm (SeMuRa) for WSN is presented in [13]. It discusses the extended version of k-connectivity to k–x-connectivity, where x is the value of threshold representing the maximal number of nodes shared between any two paths in the set of the k established paths. This protocol is based on demand routing and uses label in the datagram exchanged during the route discovery to carry the threshold.

A technique to find multiple paths between sink and multiple sources for reduced collisions is presented in [14]. It has taken the advantage of the mass deployment of sensor nodes to search for disjoint paths for multiple source nodes in order to avoid collisions.

An energy efficient and collision aware (EECA) node disjoint multipath routing algorithm for WSNs is presented in [15]. Using the location information, EECA algorithm finds two collision-free routes using constrained and power adjusted flooding and then transmits the data with minimum power needed through power control component of the protocol.

A distributed, scalable, and localized multipath search protocol to discover multiple node disjoint paths between the sink and the source node is presented in [16]. The distributed multipath routing protocol is capable to search multiple node disjoint paths. The load balancing algorithm aims to optimally allocate the traffic rate to each path.

A robust and energy efficient multipath routing protocol (REER) is presented in [17]. REER uses the residual energy, node available buffer size, and signal-to-noise ratio (SNR) to predict the best next hop through the paths construction phase. REER examines two methods of traffic allocation; the first method uses a single path among the discovered paths to transfer the data message, when this path cost falls below a certain threshold, it then switches to the next alternative path. The second method is to split up the transmitted message into number of segments of equal size, add XOR-based error correction codes, and then transmit it across multiple paths.

An energy efficient multipath routing protocol designed for WSNs is presented in [18]. This protocol tries to utilize the relaxation technique of batteries to maximize the battery lifetime and hence increases the overall lifetime of the sensor network. Relaxation periods enable the battery to recover a portion of its lost power. It uses a link cost function that depends on current residual energy, available buffer size, and link quality (in terms of signal-to-noise ratio) to predict the best next hop during the path construction phase. It routes data across multiple paths to balance the energy consumed across multiple nodes, increase the throughput and minimize packet end-to-end delay.

Non-agent based multipath routing (NABMR) and agent based multipath routing (ABMR) as hazard aware multipath reliable routing algorithms are presented in [19]. Algorithms have considered many of the sensors as well the environment parameters such as sensors energy, reliability, and hazard. ABMR is used for comparing our work; hence, a brief idea on its working is given as follows.

ABMR considers sensor nodes with their sensed parameters such as residual energy, distance, channel reliability, and importance of the sensed data to compute multiple paths from source node to destination/sink node. Mobile agents are triggered from source node, which traverse in the network to reach the destination based on sensed parameters. At each node, mobile agents migrate to neighbor nodes to gather the sensed information. The mobile agents return back to the sender and select the best node among the neighbor nodes based on sensed information and importance of the data. Once the best node is selected among the neighbors, the best node triggers the mobile agents to its neighbors to perform the task of selecting a best node. Thus, the process of best node selection continues until destination/sink node is reached. Multiple paths are computed at the destination/sink node based on paths brought by agents.

Some of the drawbacks of existing routing techniques are as follows: lack of intelligence in path discovery and path construction, lesser flexibility in relay node selection mechanisms, lack of robust mechanism for critical information transmission, etc. We have proposed an agent based intelligent multipath discovery scheme by using location information. The cost may seem to increase by including GPS (Global Positioning System) module (to obtain location information) in the sensor node. However, lot of research work has been done in the area of localization of sensor nodes by using few sensor nodes embedded with GPS modules. Use of localization technique will reduce the cost by implementing GPS modules in selected few sensor nodes. The position information advantages are much more compared to GPS module cost.

The motivations for applying this concept are as follows: This paper is inspired by data driven protocols in WSNs. In data driven network, sensors send the sensed information whenever an event is detected. Paths are dynamically constructed as and when required. Using the partial topology information received through the special intermediate nodes, sink node constructs the required number of paths. The paths can be computed based on the energy ratio, link efficiency, and hop distance. Critical information delivery in a reliable way can be assured through multipath routing.

1.2. Our contributions

Proposed location aware event driven multipath routing (LEDMPR) in WSN uses a set of static and mobile agents. Two types of software agencies are used in the scheme to find and setup the multipath in WSNs. They are node agency (NA) at each sensor node and sink agency (SA) at sink/base station.

The proposed scheme works as follows: (1) Event node computes the arbitrary midpoint between the event node and the sink node by using the location information. (2) Event node establishes a shortest path from itself to the sink node through the reference axis connecting both the nodes by using a mobile agent with the help of location information; the mobile agent collects the path information and nodes parameters on the way and provides to the sink node. (3) Finds the arbitrary location of the special (middle) intermediate nodes (above/below reference axis) by using the midpoint location information given in step 1. (4) Mobile agent clones from the event node gets the event type information and discovers the path passing through special intermediate nodes; the path above/below reference axis looks like an arc. While migrating from one sensor node to another along different paths, each mobile agent gathers the node's information in the path (such as node id, there location information, residual energy, available bandwidth, and neighbors connectivity) and delivers to the sink node. (5) The sink node constructs a partial topology connecting event and sink node by using the connectivity information delivered by the mobile agents. Using the partial topology information, sink node finds multipath and path weight factor by using link efficiency, energy ratio, and hop distance. (6) The sink node selects the number of paths among the available paths based upon the criticalness of an event. (7) If the event is non-critical, then single path with highest path weight factor is selected, else multiple paths are selected for the reliable communication.

Our contributions in this work are as follows: (1) Selection of special intermediate sensor nodes for the three paths (straight, an arc above and below the straight line) connecting event and sink node. (2) Computation of rising and falling angle by using special node's location points. (3) Usage of mobile agent for traversing through three paths by using angle and location information. (4) Consideration of joint measures such as energy efficiency, link efficiency, and hop distance for route computation. (5) Computation of the node disjoint paths based on partial topology information available around the event and sink nodes. (6) Prioritization of the node disjoint paths. (7) The performance of the proposed scheme is tested in terms of performance parameters such as packet delivery ratio, energy consumption, latency, and overhead. The proposed work is compared with ABMR.

The fundamental difference between the proposed LEDMPR and ABMR are as follows: (1) proposed LEDMPR uses only partial topology information for finding the multiple paths from source to sink node. (2) Reliable delivery of the critical information and (3) as it uses the GPS based position information, accuracy in computing the multiple paths is better.

Rest of the paper is organized as follows: Brief introduction of software agents is discussed in Section 2. Proposed scheme LEDMPR is discussed in Section 3. Simulation model for proposed scheme and the result analysis are presented in Section 4. Finally, Section 5 concludes the work and briefs future work.

2. Software agents

The traditional programming paradigm uses functions, procedures, structures, and objects to develop software for performing a given task. The paradigm does not support development of flexible, intelligent, and adaptable software's and also does not facilitate all the requirements of software development that include customization, flexibility, adaptation, reuse, etc. [20–22]. In recent developments, agent technology is making its way as a new paradigm in the areas of artificial intelligence and computing which facilitates sophisticated software development with features like flexibility, scalability, customization, and reduced network bandwidth [23,24].

Agents are the autonomous programs which sense the environment and act upon the environment using its knowledge to achieve desired goals [25–28]. The agent environment is generally referred as a host system, network, a user via a graphical user interface, a collection of other agents, or perhaps all of these combined. Agents are classified as single agent and multi-agent systems (MASs). Single agent systems comprise of a single agent interacting with resources, humans, and other processes to perform a dedicated task. MAS comprises of set of agents that interact, cooperate, and coordinate with each other to perform a set of goal oriented tasks. Mobile agents are multi-agent systems, which roam in a network and interact with each other to achieve their goals [29]. Agent platform located at a node provides the services like communication, navigation, agent creation, security, persistence, deliberation, cooperation, and collaboration.

We briefly describe the comparison of mobile agent based approach with simple message passing. Message passing is a form of communication used in concurrent computing, parallel computing, object-oriented programming, and inter process communication. Mobile agent allows processes to migrate from computer to computer where processes split into multiple instances that execute on different machines and return to their point of origin. Mobile agent computing, considered as a special case of message passing, attempts to move computations as close as possible to the data and makes efficient use of the bandwidth and energy by considerably decreasing the number of messages exchanged between cooperating applications.

3. Location aware event driven multipath routing

In this section, we describe the preliminaries, network environment, models, and agencies used for the proposed LEDMPR.

3.1. Preliminaries

Some of the key terms used in proposed LEDMPR in WSNs scheme are as follows:

- *Event node*: It is a sensor node in which the event is detected first in an event affected area. Event node triggers the process of route discovery to the sink node. A node announces itself as an event node to other neighbor nodes; this prevents other nodes to assume the role of event node in the event affected area.
- *Midpoint*: It is an arbitrary middle point on an arbitrary straight line connecting event node and a sink node. Special intermediate nodes are chosen above and below the midpoint where all the points almost lie in a straight line.
- *Special intermediate nodes*: These are the sensor nodes located above and below the midpoint between sink and event nodes.
- *Rising Angle:* It is an angle between event node and special intermediate node above the reference positive x-axis (an axis connecting the event node and sink node). Also, messages traverse with the rising angle from special intermediate node (located below midpoint or reference axis) until they reach the sink node (see Fig. 2 for clarity).
- *Falling angle*: It is an angle between event node and special intermediate node below the reference positive x-axis. Also, messages traverse with the falling angle from special intermediate node (located above midpoint or reference axis) until they reach the sink node.
- *Hop count:* It is the total number of relay (intermediate sensors) nodes between the event node and the sink node.

3.2. Network environment

The network environment considered for proposed work is shown in Fig. 1. It consists of tiny sensor nodes with heterogeneous data sensing capability and a sink node. Sensor nodes are geographically distributed. Whenever the sensor node detects an event, they send the data to sink node by using wireless multihop communication. We assume that all the nodes in the network (sensor nodes and sink node) are static. During deployment phase, all sensor nodes have same energy. It is assumed that sensor nodes have capability to reconfigure the transmission power. In the proposed LEDMPR work, we assume that only few sensor nodes with GPS are deployed and rest of the nodes use localization algorithm to find their positions. Using the GPS information from a sensor node which has GPS module, sensor nodes estimate their approximate location [30,31]. This process reduces the cost of the proposed system. Practically, GPS achieves relative position and motion of individual nodes within the network with sub-centimeter accuracy [32]. Each sensor node consists of an agent platform with security features to coordinate the inter-agent communication. A sensor node (active nodes) participates in aggregation if and only if the sensed values in a particular time window drift by a given threshold.

3.3. Models

This section presents link parameters, partial topology discovery, and path discovery that are used in the proposed scheme.

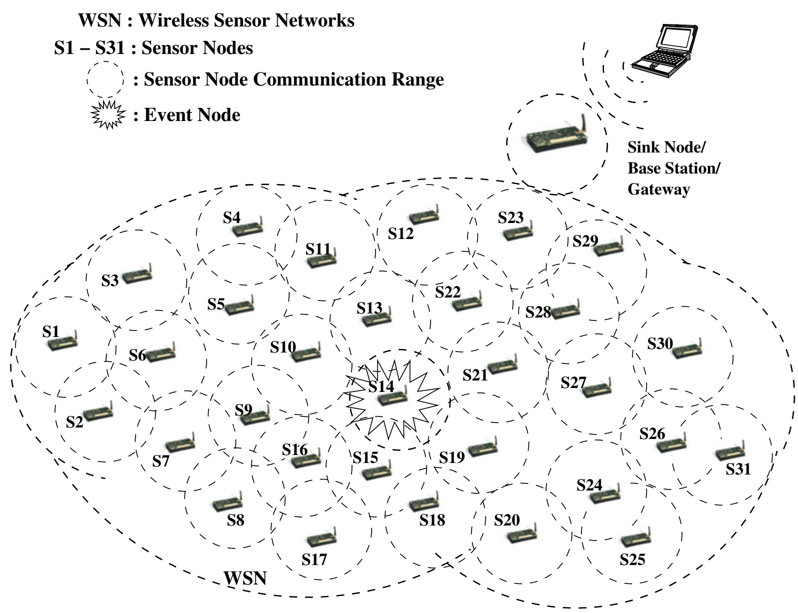

Figure 1 Network environment.

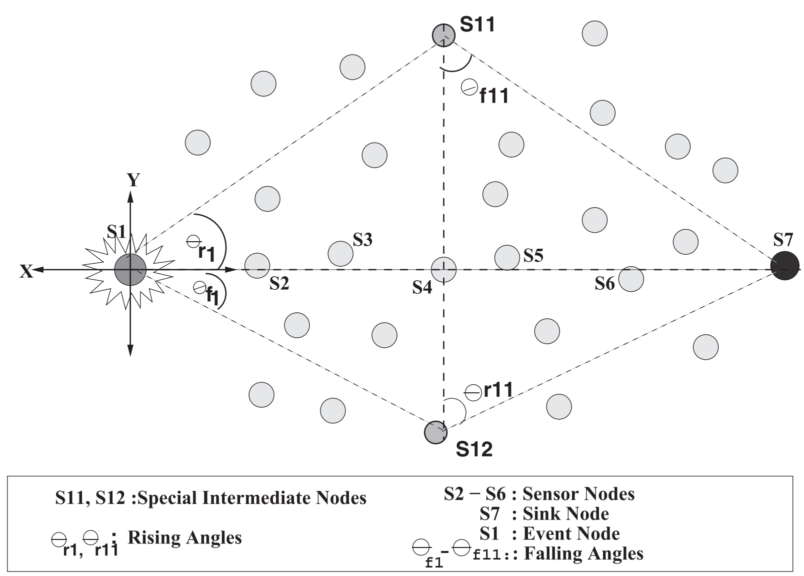

Figure 2 Partial multipath discovery in WSNs.

3.3.1. Path parameters

This section depicts the computation of path parameters such as link and path efficiency, energy ratio, and hop distance factor, which are used in the proposed scheme.

Link efficiency can be computed as follows. Let C be capacity of a discrete-time discrete-valued channel, B be the bit rate of a channel, E_i be the total energy consumed for transmission of a bit in link i, SNR be the signal-to-noise ratio [33]. Capacity of channel "i" is computed by using:

$$C_i = B\log_2(1 + SNR) \tag{1}$$

Let E_t be the energy consumed for the transmission of a bit per distance d. E_i can be computed by using Eq. (2) [33].

$$E_i = E_t \times d \tag{2}$$

Link efficiency ($Leff_i$) can be computed by using Eq. (3) [34].

$$Leff_i = \frac{C_i}{E_i} \tag{3}$$

Path efficiency (P_{eff}) can be computed by using Eq. (4) by considering "n" links on the path.

$$P_{eff} = \mathrm{Min}\{Leff_1, Leff_2, \ldots, Leff_n\} \tag{4}$$

Energy ratio in each of the path from event node to sink node is computed as follows: Let $ER(1)$ to $ER(n)$ be the residual energy of the "n" intermediate nodes of a path. The minimum ($ER_{\min}$) and maximum ($ER_{\max}$) of the residual energy for "n" nodes in the path is computed by using Eqs. (5) and (6). And path energy efficiency (E_{ef}) is given by Eq. (7).

$$E_{R_{\min}} = \mathrm{Min}\{E_R(1), E_R(2), \ldots, E_R(n)\} \tag{5}$$

$$E_{R_{max}} = \mathrm{Min}\{E_R(1), E_R(2), \ldots, E_R(n)\} \tag{6}$$

$$E_{ef} = \frac{ER_{\min}}{ER_{\max}} \tag{7}$$

The hop distance factor (Hdf) of a path is computed by using Eq. (8), where Euclidean path distance from event node to sink node is Pd and total number of hops in a path from event node to sink node is Phc.

$$Hdf = \frac{Pd}{Phc} \tag{8}$$

3.3.2. Partial topology discovery

Fig. 2 shows the multipath partial topology discovery from an event node to sink node. S1 and S7 are the event node and sink node, respectively. S2–S4 sensor nodes and S4–S7 are situated at angle of 0° with reference to X-axis. Sensor node S4 is the arbitrary midpoint node. Sensor nodes S11 and S12 are the special intermediate sensor nodes situated almost perpendicular to the reference X-axis. Event node finds the midpoint location of S4 by using Eqs. (9) and (10) by considering (xe, ye) and (xs, ys) as location information of the event node and sink node, respectively.

$$x_{mid} = \frac{x\mathrm{s} + \mathrm{xe}}{2} \tag{9}$$

$$y_{mid} = \frac{y\mathrm{s} + \mathrm{ye}}{2} \tag{10}$$

Event node finds the special intermediate nodes (SINs) perpendicular to the x-axis from the midpoint. Let (x'_{mid}, y'_{mid}) and (x''_{mid}, y'') be locations of SINs S11 and S12, respectively, in which $x'_{mid} = x_{mid}$ and $x''_{mid} = x_{mid}$. y'_{mid} and y''_{mid} are computed by using Eqs. (11) and (12), respectively.

$$y'_{mid} = n \times R + y_{mid} \tag{11}$$

$$y''_{mid} = y_{mid} - n \times R \tag{12}$$

where "n" and "R" are degree of neighbors and communication range of sensor node, respectively.

Event node finds the rising and falling angle by using:

$$\theta_{r1} = \tan^{-1}\frac{y'_{mid} - ye}{x'_{mid} - xe} \quad \text{if } (x'_{mid}) > Xe \tag{13}$$

where θ_{r1} is the rising angle.

$$\theta_{f1} = 2\pi - \theta_{r1} \tag{14}$$

We consider $\theta_{f11} = \theta_{f1}$ and $\theta_{r11} = \theta_{r1}$ to be the alternate angles. Agents are moved on the three paths from event node to sink node to collect the parameter information from the nodes as well as neighbors, which will be used by the sink node to construct a partial topology and find the multipath.

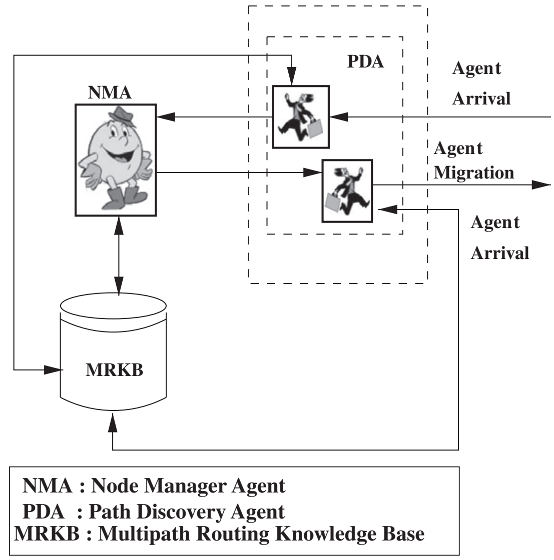

Figure 3 Node agency.

3.4. Agency

The proposed work uses a set of static and mobile agents for path discovery and path computation, which are part of the sensor node and sink node agencies. This section presents the agencies and corresponding agents.

3.4.1. Node agency

It comprises of Node Manager Agent (NMA), Path Discovery Agent (PDA), and Multipath Routing knowledge Base (MKRB) for inter-agent communication. NMA is static agent, whereas PDA is the mobile agent. The components of the node agency and their interactions are depicted in Fig. 3.

Multipath Routing knowledge Base (MKRB): it is the knowledge base which can be read and updated by agents. It comprises of node id, active/sleeping mode, residual energy, distance between the neighbor nodes, sink node id, SINs id's, location information of sink node and SINs, event sensing time, signal strength, available bandwidth, distance between itself and sink node, rising and falling angles. It also maintains the neighbor nodes information such as node id and location information. The event sensor node maintains the path(s) information from itself to sink node as given by the sink node agency.

Node Manager Agent (NMA): it is a static agent that resides in all the sensor nodes of WSN. It monitors the information available such as signal strength, transmission range, residual energy, and time stamp. The parameters link efficiency, minimum and maximum residual energy, and distance as discussed in Section 3.3.1 are computed by NMA. It checks for event detection, if an event is detected, it computes the arbitrary midpoint and SINs with the reference axis between the event triggered node and the sink node as discussed in Section 3.3.2. NMA creates PDA and MKRB. NMA uses MKRB to update the path information. NMA makes the node to operate in sleeping and active mode. In sleeping mode, node does not transmit any data. If residual energy is decreasing, then NMA sends the status of the energy to its nearest sensor node.

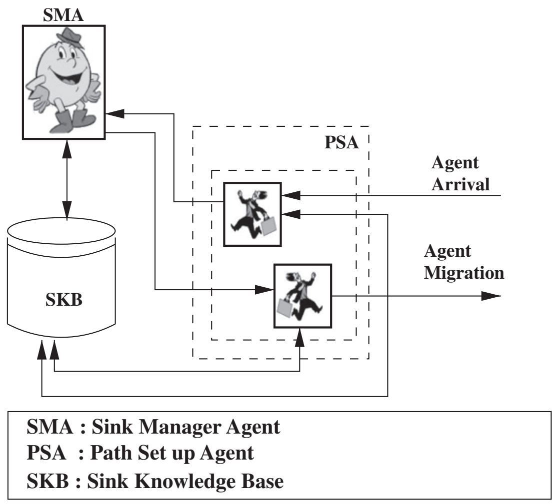

Figure 4 Sink node agency.

NMA gets the neighboring node information such as node id, location, and updates the MKRB.

Path Discovery Agent (PDA): whenever an event is detected, NMA of the event node triggers a PDA (mobile agent) from event node. Three clones of PDA are sent for the path discovery as shown in Section 3.3.2. A clone is copy of the parent agent. While migrating, PDA collects the path information such as residual energy of intermediate sensor nodes, distance between the sensor nodes and the hop count; it also collects all the neighbor's information. PDAs traverse network in three directions. First PDA traverses with almost zero degree angle until it reaches the sink node. The second one traverses until it reaches the SIN node with rising angle and from SIN node, it migrates with falling angle to reach the sink node. The third PDA traverses until it reaches the SIN node with falling angle and from SIN node, it migrates with rising angle to reach the sink node. Finally, PDAs deliver the collected partial topology information to the sink node.

3.4.2. Sink node agency

The sink node agency consists of Sink Manager Agent (SMA), Path Setup Agent (PSA), and Sink Black Board (SBB) for inter-agent communication. The components of the sink agency and their interactions are depicted in Fig. 4.

Sink Knowledge Base (SKB): it is the knowledge base that can be read and updated by SMA, PDA, and PSA. It stores the network related information such as path length, hop count, residual energy, minimum and maximum value of the residual energy of each path, available bandwidth, channel capacity, number of available paths to the event node, path weight factor, etc.

Sink Manager Agent (SMA): it is a static agent residing in sink node that monitors the network related information such as all sensor node's id, number of active nodes, and available path information to reach event node. Based on the collected information such as residual energy, available bandwidth, hop count for each path, and path distance, it is responsible to compute the node disjoint paths from sink node to the event node (as discussed in Section 3.3.2). It computes path weight factor of each path. Depending on the type of event, it decides

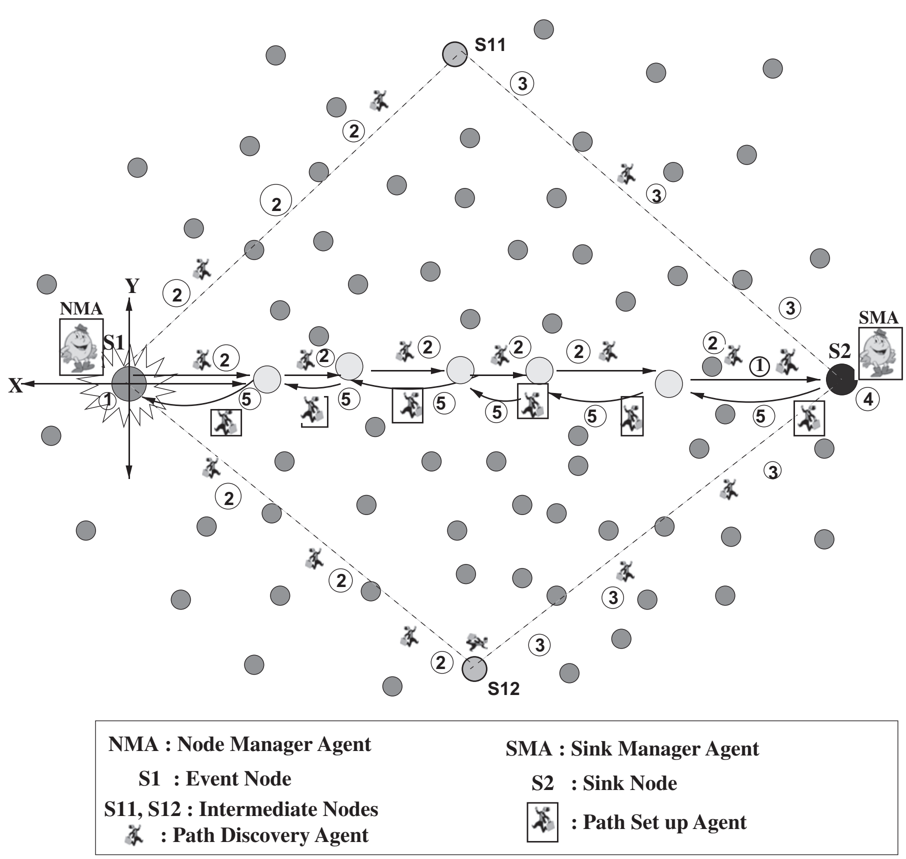

Figure 5 Example scenario.

to choose more than one path. Multipaths are prioritized based on path weight factor. If event is critical, multipath is used to send PSAs. Each PSA traverses on one path. To reduce the overheads, we have considered maximum of three best disjoint paths.

Path Setup Agent (PSA): it is the mobile agent triggered by the SMA. It gets the path information from the SKB and traverse to the event node to verify the nodes on the path for the considered parameters. After reaching the event node, it updates the MKRB with path information.

3.4.3. Example scenario

This section presents the operation of the proposed scheme to realize some of the application scenarios. Sample example scenario is as shown in the Fig. 5. The numbers in the figure indicate operation sequence number. It comprises of sensor nodes, event node (S1), sink node (S2), and SINs (S11 and S12). The operation sequence is as follows:

1. Whenever an event is generated at the sensor node S1, NMA of the event node initiates the path discovery process to the sink node.
2. NMA generates PDA; PDA generates three clones of PDA and their angle of traversal; clones 1, 2, and 3 traverses until they reach the sink node, S11 and S12, respectively. During PDA migration, they collect the path information.
3. From SINs S11 and S12, PDA clones 2 and 3 change their angle of traversal. They deliver path information to the sink node.
4. SMA of the sink node computes the disjoint multipath to event node. It prioritizes the paths by computing the path weight factor to each of the disjoint path.
5. SMA triggers the PSA on the best path considering non-critical event, which migrates to event node.

4. Simulation

To test the performance effectiveness of the proposed work, we have simulated the proposed scheme for various network scenarios using *C* programming language with a confidence interval of 95%. A comparison of the proposed scheme with the existing agent based (ABMR) multipath routing scheme [19] is perform. In this section, simulation model, performance parameters, and result analysis are presented.

4.1. Simulation model

Network model: we considered an area of $l \times b$ square meters for WSN. A network consists of N static nodes that are randomly placed within a given area. The bandwidth is $BW_{single\text{-}hop}$ for a single hop connected sensor nodes.

Channel model: S-MAC protocol [35] is used for media access. The transmission of packets is assumed to occur in discrete time. A node receives all packets heading to it during receiving interval unless the sender node is in "non-active" state. For simplicity, we have considered the channel to be error free.

Propagation model: free space propagation model is used with propagation constant β. Transmission range of WSN node (communication radius) is R for a single hop distance. It is assumed that at any given time, the value of transmitted energy per packet is E_u Joules for every node. R is directly proportional to E_u of the node, that is, $R = CE_u$, where constant of proportionality C depends on the medium of communication, attributed to β.

Table 1 Simulation inputs.

Parameters	Notations	Values
Length	l	5000 m
Breadth	b	5000 m
Number of nodes	N	200
Transmitting Nodes	Nt	40–200
Propagation constant	β	2.5
Sensor node communication range	R	300–500 m
Rising angle threshold	θ_{rth}	0–5°
Falling angle threshold	Θ_{fth}	0–5°
Initial energy of sensor node	E_f	1 KJoules
Number of packets per seconds	Tr_{pkts}	256 per second
Bandwidth per hop	$BW_{single\text{-}hop}$	5 Mbps
Size of sensed data at each node	S_d	5 Kbytes
Size of the processing code	S_{proc}	3 Kbytes

5. Simulation procedure

Table 1 presents the simulation parameters considered for analyzing the scheme. Simulation procedure involves following steps.

1. Generate sensor network environment.
2. Event node sends the partial topology information to sink node.
3. Apply the proposed scheme.
4. Compute performance parameters of the system.

The following performance parameters are assessed.

Packet delivery ratio: it is a ratio of packets received to packets sent.

Energy consumption: it is the total energy consumed for the path discovery, path setup and sending data from event node to sink node. It is expressed in terms of milliJoules.

Latency: it is the total time taken to transmit the data from event node to sink node. It is expressed in terms of milliseconds.

Number of paths: it is the total number of node disjoint paths between the event node and the sink node.

Overhead: it is the additional code which acquires the communication channel.

6. Results

This section presents the results obtained during simulation. We compare results of proposed work with an existing agent based multipath routing scheme for WSNs.

6.1. Packet delivery ratio and energy consumption

Fig. 6 presents packet delivery ratio (PDR) for given number of nodes involved in transmission and the communication range. The PDR decreases with increase in number of transmitting nodes and increases with increase in communication

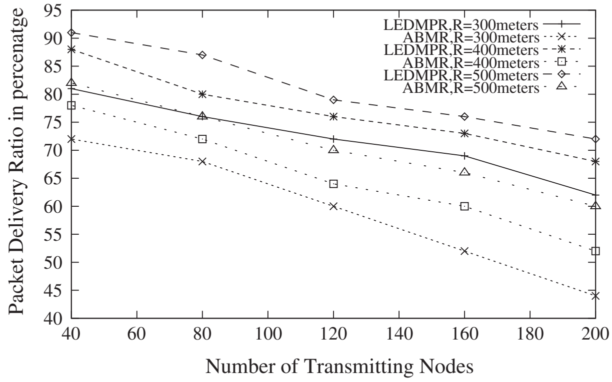

Figure 6 Packet delivery ratio vs. number of transmitting nodes.

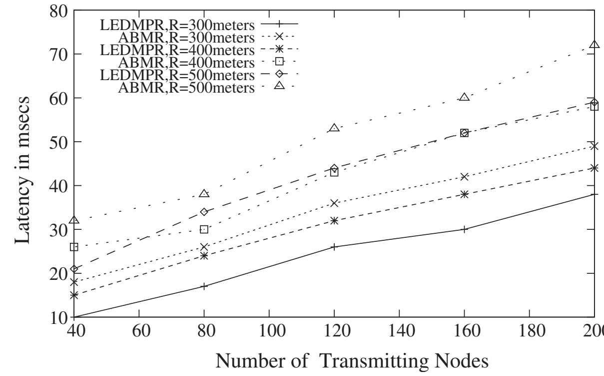

Figure 8 Latency in milliseconds vs. number of transmitting nodes.

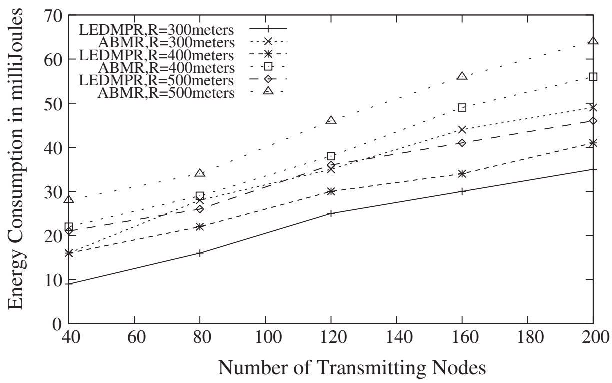

Figure 7 Energy consumption in milliJoules vs. number of transmitting nodes.

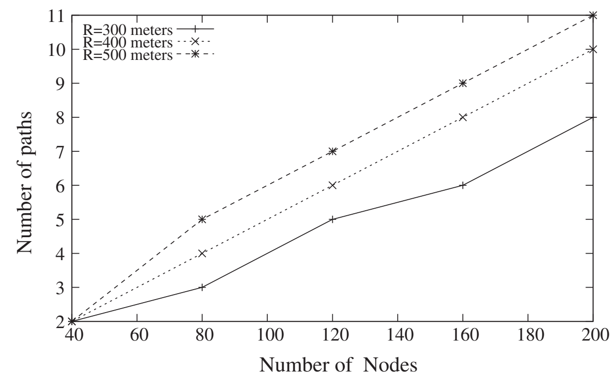

Figure 9 Number of paths vs. number of nodes ($n = 3$).

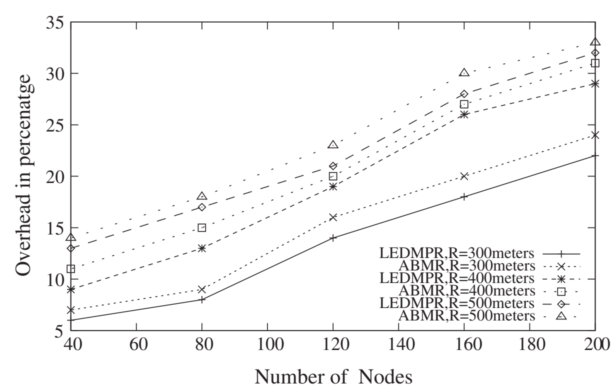

Figure 10 Overhead in percentage vs. number of nodes (critical).

range for both ABMR and LEDMPR. However, LEDMPR exhibits good PDR as compared to ABMR. The amount of data generated increases with increase in number of transmitting nodes; this causes more bandwidth requirements. Hence, available bandwidth may not be sufficient for successful transmission of the data thereby causing decrease in PDR. LEDMPR scheme provides good bandwidth availability than ABMR since it considers link efficiency for reliable path computation. PDR in LEDMPR is better with higher transmission range due to reduction in number of isolated nodes.

Fig. 7 explains the energy consumption for the given number of transmitting nodes and the transmission range. With increase in the number of nodes and communication range, the energy consumption increases in both ABMR and LEDMPR. LEDMPR performs better compared to ABMR. Energy consumption is due to gathering of partial topology information, path computation, path information transmission, and reception. The proposed LEDMPR scheme exhibits less energy consumption because it uses partial topology, hop distance factor, and energy information (energy efficiency) gathering for path computation. ABMR uses only topology information and hazard nodes for path computation.

6.2. Latency and number of paths

Fig. 8 describes the latency for the given number of transmitting nodes and the communication range. As the number of transmitting nodes and the communication range increase, time required to gather and compute the multiple disjoint path will also increase. LEDMPR takes less time than ABMR in computing paths. As the proposed LEDMPR uses only partial topology information for finding the paths, the latency involved will be less unlike the ABMR which uses full topology information. The path distance between the source node and sink node is computed using the special intermediate nodes. Path distance in LEDMPR is less as compared to the ABMR.

Fig. 9 shows the number of available node disjoint paths in LEDMPR with given number of nodes in the network and the

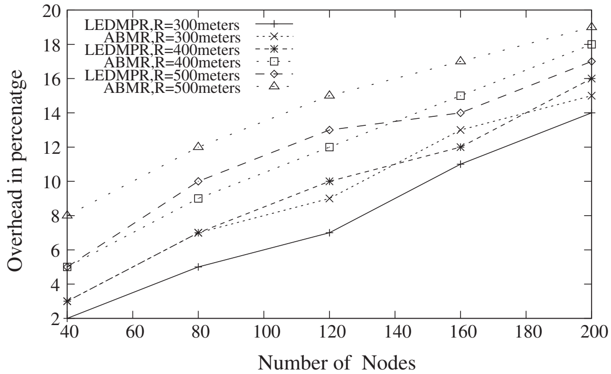

Figure 11 Overhead in percentage vs. number of nodes (non-critical).

communication range. The disjoint paths increase with increase in number of nodes and transmission range. This happens due to agents moving in three different directions and collects the third degree neighbor information. Higher the degree of neighbors, probability of getting more disjoint paths increases.

6.3. Overhead

Figs. 10 and 11 present the overhead with the given number of nodes and communication range for critical and non-critical data communication. Overhead increases with increase in transmission range and the number of nodes. With increase in the number of nodes and communication range, the number of transmissions and computations increase. LEDMPR has less overhead compared to ABMR. For critical information communication, LEDMPR uses multipath routing in order to achieve the reliable communication, whereas non-critical information communication uses the single path with highest weight factor. As the proposed LEDMPR uses agents movement in restricted directions to get partial topology information, the number of transmission for finding the multipath is reduced as compared to the ABMR.

7. Conclusions

The proposed scheme presented a location aware event triggered disjoint multipath routing in WSN by employing a set of static and mobile agents. An event node triggers the path discovery mechanism by computing the special intermediate nodes between event node and the sink node dynamically. The scheme used set mobile agents for gathering partial topology information connecting event and sink node by using location information. The partial topology information is used in computing the node disjoint paths. For node disjoint path, the sink node computes the path weight factor based on the path efficiency, energy ratio and hop distance factor. For critical information, sink node sends multipath information, whereas single path with highest weight factor information is sent for non-critical information to the event node. As compared to ABMR, the proposed LEDMPR performed better in terms of packet delivery ratio, energy consumption, overhead and latency. The work can be extended by considering mobile sensor and sink nodes, and aggregation mechanism employment based on type of information.

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