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Starfish Routing for Sensor Networks with Mobile Sink

Md. Ahsan Habib, Sajeeb Saha, Md. Abdur Razzaque, Md. Mamun-or-Rashid,
Giancalro Fortino[b], Mohammad Mehedi Hassan[c,d,*]

[a]*Green Networking Research Group, Department of Computer Science and Engineering,*
University of Dhaka, Bangladesh
[b]*Department of Informatics, Modeling, Electronics, and Systems, University of Calabria, Italy*
[c]*Chair of Pervasive and Mobile Computing, College of Computer and Information Sciences,*
King Saud University, Riyadh, Saudi Arabia
[d]*Information Systems Department, King Saud University, Riyadh, Saudi Arabia*

Abstract

Wireless Sensor Networks (WSNs) with mobile sinks were proven to provide extended network lifetime and better data delivery services. This was achieved by minimizing routing costs and avoiding development of any hot-spot zones in the network. However, existing routing strategies in the literature have limitations to offer end-to-end data delivery delay and throughput required by the real-time sensing and monitoring applications. In this paper, following the principle of water vascular system of a Starfish, we have designed a routing backbone consisting of a central *ring-canal* and a number of *radial-canals* across the network. The radius of the *ring-canal* and the number of *radial-canals* are dynamically determined based on the transmission range of sensor nodes and size of the network. The proposed *Starfish routing backbone* guarantees that each source sensor node gets single-hop access to a backbone node, which in turn facilitates to reduce data delivery delay and increases fairness of energy consumption load distribution on network nodes. The results of the simulation experiments, carried out in NS-2, prove the efficiency of the proposed *Starfish routing backbone* in terms of end-to-end data delivery delay, throughput and energy consumption compared to state-of-the-art works.

Keywords: *Wireless Sensor Network (WSN), Mobile sink, Starfish routing backbone, End-to-End delay, Markov chain model, Network lifetime.*

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[*] Corresponding author, Email: mmhassan@ksu.edu.sa

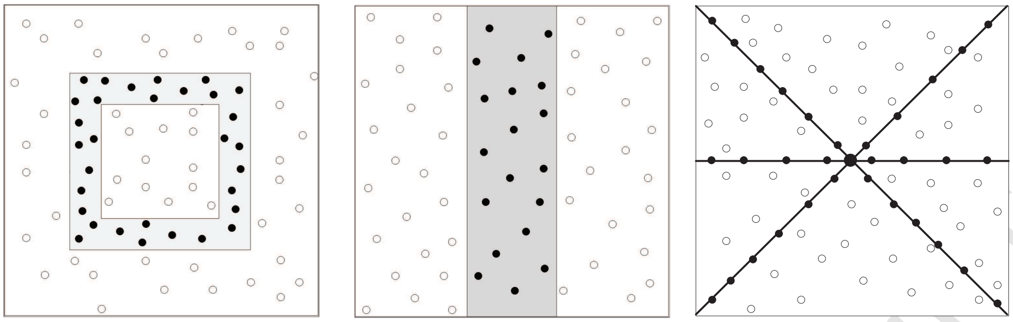
1. Introduction

In recent years, the augmentation of extraordinary computing and communication features in sensor motes has helped Wireless Sensor Networks (WSNs) to expand continuously from small scale applications [1] to large scale infrastructure, emergency medical response, military surveillance, agricultural monitoring and sensor-data cloud applications [2, 3, 4, 5, 6]. However, forming a routing backbone for a given network that facilitates timely and energy-efficient data gathering from source sensor motes to the sink is a great challenge [7, 8]. In this paper, we develop a data routing backbone for a WSN that offers reduced end-to-end packet delivery delay and uniform energy consumption for extended network lifetime.

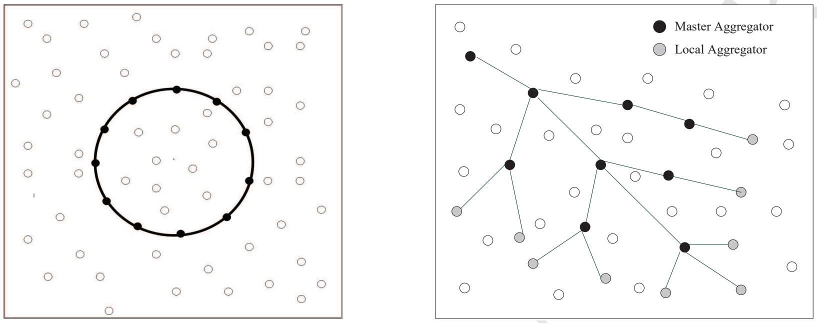
Routing strategies in the literature considering *static sink* suffer from network partitioning problem due to creation of hot-spot zones near the sink [9, 10, 11, 12, 13, 14]. Some very recent works have demonstrated the effectiveness of *mobile sink* based routing strategies in increasing both the data delivery performances and network lifetime [15, 16, 17, 18, 19, 20, 21]. These works have also demonstrated that sink mobility ensures data network connection under sparse and disconnected sensor networks. However, the sink mobility invites the problem of locating the destination sink in real time and to establish source-sink routing backbone so as to achieve reduced end-to-end packet delivery delay and increased data delivery throughput.

Mobile sink based routing strategies in the literature can largely be divided in two groups: *rendezvous-based* and *backbone-based*. In the first category, railroad [15], line [16] or hexagon [17, 22] like rendezvous regions are constructed, as shown in Fig. 1(a),(b),(c), respectively, where each rendezvous node collects data from source sensor nodes, stores it and later forwards to the sink node upon request. However, the rendezvous regions in these protocols suffer from storing data for long time, data persistence against node failure, reliability and hot-spot problems due to flooding or broadcasting within the rendezvous area. In the second category of works, a routing backbone is formed, where each source sensor node acquires the updated sink position from the backbone (e.g., ring [18], fishbone [19]), as shown in Fig. 1(d),(e), and forwards data to the sink in multi-hop fashion. However, these protocols are criticized by their lacking in scalability and higher data delivery delays.

In this paper, we introduce *Starfish routing*, a novel strategy for constructing routing backbone, where *ring*- and *radial-canals* are constructed (analogous to the water vascular system of a Starfish [23]) in such a way that any source node can access one of the backbone nodes in one hop. The *ring-canal* helps to alleviate



(a) Railroad [15] (b) LBDD [16] (c) HexDD [17]



(d) Ring [18] (e) Fishbone [19]

Figure 1: Routing strategies for sensor networks with mobile sink

the hot-spot problems and *radial-canals* facilitate faster data delivery towards the sink. A preliminary version of this work is published in [24], which has now been extensively enhanced by augmenting updated *ring-canal* construction model, theoretical analysis of the performances and exhaustive simulation studies. The key contributions of the proposed *Starfish backbone* development strategy are summarized as follows:

- We construct a *Starfish*-like routing backbone in the network so that any source node can directly access one of the backbone nodes, reducing the end-to-end packet delivery delay.
- The construction of *ring-* and *radial-canals* of the proposed *Starfish backbone framework* is mathematically modeled and thus it is scalable.
- A statistical analysis for expected end-to-end packet delivery delay in *Starfish routing backbone* has been carried out considering both hop distance to the sink and number of retransmission attempts.

- The performances of the proposed *Starfish routing backbone* have been carried out in Network Simulator version-2 (NS-2) [25] and significant performance improvements are observed for both event-driven and periodic data reporting applications.

The remainder of the paper is organized as follows. Section 2 contains a study on the state-of-the-art works and an explicit insight into the proposed *Starfish routing backbone* is presented in Section 3. An analytical model using *Markov chain* is developed to investigate the average end-to-end packet delivery delay of *Starfish routing* in Section 4. The Section 5 discusses on the performance evaluation results and finally, we conclude the paper in Section 6.

2. Related Works

In the literature, we have found a good number of routing strategies for sensor networks with mobile sink and those can largely be categorized into two groups: *rendezvous-based* [15, 16, 17] and *backbone-based* [18, 19].

Among the *rendezvous-based* approaches, in Railroad routing [15], a rectangular region is constructed in the network, as shown in Fig. 1(a), to store metadata of the source node. When a source senses data, it stores locally and sends metadata to the railroad. While the sink requires data, it sends a unicast query to the railroad. Upon receiving this query, the railroad acquires data from the source and transmits to the sink through unicast path. This protocol suffers from higher latency due to traveling longer path using unicast query and data loss for node failure. To mitigate data loss problem from a source node in [15], a vertical strip of nodes is created to store data in Line-based Data Dissemination protocol (LBDD) [16], as shown in Fig. 1(b). The vertical region in [16] splits the network into two equal portions. When a source senses data, it immediately sends data to the inline nodes of the vertical region. Later, while the sink queries data, the inline nodes broadcast the query in the rendezvous region and the corresponding inline node sends back the required data in reverse path. However, this protocol suffers from higher latency for boundary nodes in a large network because of having single central zone. Besides, broadcasting in the central zone decreases the network lifetime significantly. One key difference between Railroad [15] and LBDD [16] protocols is that the queries issued by the sink in the Railroad travel by unicast transmission rather than broadcast. However, the expected data delivery delay in Railroad protocol is higher than that in LBDD [16] since the queries travel longer paths in Railroad [15].

These problems are further addressed in HexDD protocol [17] to enhance the network performances by creating six rendezvous regions along three principal diagonals in the network passing through the center cell, as shown in Fig. 1(c). These regions replicate and store data while sending data toward the central intersection node over the closest principal diagonal lines. To retrieve data, the sink queries over the rendezvous region. If requested data exists in any rendezvous node, it sends data back to the sink through the reverse path of the sink's query forwarding. However, this protocol suffers from hotspot problem, especially in the central zone, because all data and queries are transmitted through the central node. Besides, the fixed six rendezvous regions, irrespective of network size, cause imbalance energy consumption on few rendezvous nodes in the network. Recently, some other variants of rendezvous based protocols [22, 26, 27, 28] have been proposed; but none of those can avoid hotspot problem.

In case of *backbone-based* approach, a routing backbone is developed in the network to acquire the fresh sink position and to transmit data toward it [18, 19, 29, 30, 31, 32, 33, 34]. In Ring routing [18], a closed loop of nodes is constructed that encapsulates a globally predetermined network center, as shown in Fig. 1(d). As soon as the mobile sink changes its position, it advertises updated location to the ring by forwarding packets towards the network center and thus the source nodes can acquire sink's fresh position from the ring. Later, the source nodes send data directly to the sink in multihop fashion. Though this routing backbone offers quicker localization of the sink, its scalability is questionable for large networks. Moreover, it has not explored appropriate ring-radius with respect to network size or communication range of sensors. Experimental results show that, if the ring radius is too small, the sink localization time is greatly increased for network border nodes. The same problem occurs for central nodes when a large ring-radius is chosen. The backbone is effective not only for faster localization of the sink but also to provide energy-efficient data delivery to the sink. In [19], the Fishbone routing backbone is constructed using different levels of aggregators (e.g. master and local aggregators), as shown in Fig. 1(e). The source nodes transmit data over the backbone in multihop forwarding. Though the above backbones provide better communication infrastructures, the offered end-to-end data delivery latency is higher due to lack of choosing optimal ring-radius in [18] and multi-level aggregation in [19].

Motivated by the above challenges of routing data packets from source nodes to the mobile sink in WSNs, in this paper, we have developed *Starfish routing backbone* aiming to offer reduced data delivery delay and enhanced network lifetime. The nice performances are achieved by constructing *ring-canal* and *radial-*

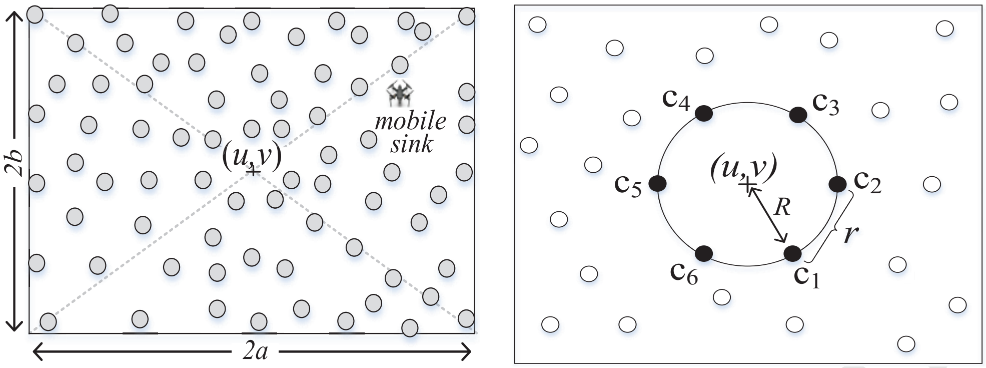
canals in the network, analogous to the water vascular system of a Starfish [23]. The *ring-canal* is constructed based on sensor's transmission range and the *radial-canals* are formed depending on both network size and transmission range. The existence of *central ring-canal* with a number of *radial-canals* jointly helps to distribute data routing loads to many nodes of the network. Such a policy has multidimensional benefits including extended network lifetime, faster data delivery to the sink node, reduced operational overhead and finally the increased throughput. What we unfold in the next section is the operational details of *Starfish routing backbone*.

3. Proposed Starfish Routing Backbone

The development of an efficient routing backbone for wireless sensor network is not only important to reduce the end-to-end data delivery delay but also to extend the network lifetime to great extent. The key philosophy of designing the proposed *Starfish routing backbone* is to spread the backbone nodes over the different regions of the network in such a way that a source node can access at least one of the backbone nodes directly. In this section, the construction and operational details of *Starfish routing backbone* are presented followed by the assumed network model.

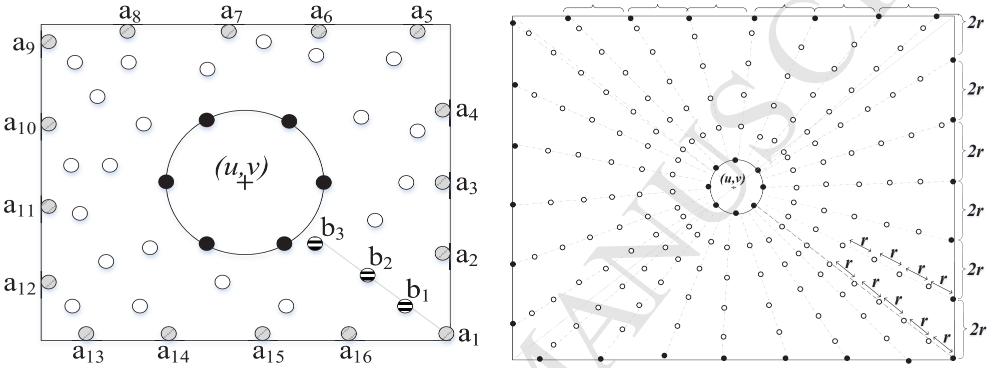
3.1. Network model

We assume a wireless sensor network where homogeneous sensor nodes are randomly distributed in a rectangular network size of $\mathbf{2a} \times \mathbf{2b}$, as shown in Fig. 2(a), where $\mathbf{a}$ and $\mathbf{b}$ $(\mathbf{a} \geq \mathbf{b})$ are the half of the length and width of the rectangle, respectively, and (u,v) is the center of the network. All sensor nodes are considered as stationary after deployment, while the sink is mobile, i.e., the sink moves randomly in the network and collects data from sensor nodes. Each sensor node i has an initial energy E_0 and has the same transmission range r. We also assume that each sensor node knows its own coordinate point (x_i, y_i) using GPS or any localization method [35, 36]. The source sensor nodes forward sensed data packets to the mobile sink over the backbone nodes in multihop fashion. The proposed *Starfish routing backbone* consists of a central *ring-canal* and a number of *radial-canals* prolonged across the network. The nodes on the routing backbone are divided into three categories: a set of *anchor nodes* at the network edge, $Z_a = \{a_1, a_2, \ldots, a_{16}\}$; a set of *radial-canal nodes*, $Z_b = \{b_1, b_2, b_3, \ldots\}$; a set of nodes on the *ring-canal*, $Z_c = \{c_1, c_2, \ldots c_6\}$; and $Z = \{Z_a \cup Z_b \cup Z_c\}$ represents the set of all nodes on the *Starfish routing backbone*, as shown in Fig. 2(b),(c).



(a) Network model

(b) Ring-canal nodes



(c) Anchor and Radial-canal nodes

(d) Starfish routing backbone

Figure 2: Network model and construction of Starfish routing backbone

In *Starfish routing backbone*, the *ring-canal* is constructed based on the transmission range *r* of the sensor nodes and several *radial-canals* are formed depending on both network size and transmission range *r*. During construction of *Starfish routing backbone*, the backbone nodes are selected based on the node's initial energy E_0, residual energy E_{res}, and energy threshold E_{th} for successful transmission of the nodes. The main responsibility of backbone nodes on the *ring-canal* and *radial-canals* is to collect data from the source sensor devices within 1-hop and forward those toward the *mobile sink node*. The detail construction procedure of the *ring-canal* and *radial-canals* is presented in the following subsections. The notations used in this paper are summarized in Table 1.

Table 1: List of notations

Symbols	Description
$2a \times 2b$	Area of the network
r	Transmission range of a sensor node
Z	Set of all backbone sensor nodes
Z_a	Set of anchor nodes on network edge
Z_b	Set of radial-canal nodes
Z_c	Set of ring-canal nodes
R	Radius of the ring-canal
ϕ	Control variable for ring-canal radius
θ_1, θ_2	Incident angles of radial-canals on principal-axes
E_0	Initial energy of a sensor node
E_{res}	Residual energy of a sensor node
E_{th}	Energy threshold for backbone nodes

3.2. *Construction of ring-canal*

A central *ring-canal* is a closed loop of nodes circularly located around the center of the wireless sensor network, as shown in Fig. 2(b). The primary objective of *ring-canal* is to alleviate the hot-spot problem, specially in the network center, due to the convergence of backbone nodes at center. If the *ring-canal* size becomes extraordinarily large with respect to the network size, the source nodes inside the *ring-canal* cannot access its backbone node directly. Meanwhile, if the *ring-canal* size is very small with respect to transmission range, it increases more interference and collision during transmissions from many nodes near to network center. This happens due to existence and convergence of more *radial-canals* onto the *ring-canal* of the *Starfish routing backbone*. We define the radius of a *ring-canal* as follows,

$$R = \phi \times r, \tag{1}$$

where, $0 < \phi \leq 1$, is a control variable that determines the amount of expansion of the radius of *ring-canal* from the transmission range of a sensor. We have studied the behavior of this control variable in Section 5. The center of the *ring-canal* is fixed at the network center *(u,v)* and thus a set of nodes, $Z_c = \{c_1, c_2, \ldots, c_6\}$, located at any (x,y) position (or at very nearby) encapsulate the network center, as shown in Fig. 2(b), to preserve its circular property as follows,

$$(x-u)^2 + (y-v)^2 = R^2. \tag{2}$$

Now, in order to construct the *ring-canal* of the proposed *Starfish routing backbone*, at first, the central controller determines the network center *(u,v)*, *ring-canal* radius R using Eq. 1 and sketch a reference circle using Eq. 2. The controller then picks a sensor node randomly on or somewhat inside reference-circle as the starting node (i.e., c_1) of the *ring-canal*, as shown in Fig. 2(b). Later, the next nodes are selected (i.e., c_2 to c_6) every after the distance equal to transmission range r (or somewhat less than r) lying on or inside the reference-circle maintaining the property stated in Eq. 2 and minimum energy threshold (E_{th}), i.e., $E_{res} \geq E_{th}$, where, E_{res} is the residual energy of a sensor node.

This selection process of *ring-canal* backbone nodes continues until the starting node of the *ring-canal* is reached. These backbone nodes on the *ring-canal* in Z_c (i.e., c_1 to c_6), form a complete loop of connected nodes, as shown in Fig. 2(b). The shape of the *ring-canal* doesn't need to be a proper circle but it must be a connected closed loop of nodes.

3.3. Construction of radial-canals

In *Starfish routing backbone*, the *radial-canals* are prolonged toward the edge of the network from the *ring-canal*. The primary objective of constructing *radial-canals* is to spread the backbone nodes across the network so that the source nodes from all areas of the network can access at least one of the backbone nodes on *radial-canals*. If the backbone nodes are located far away from a particular source node, it takes higher time to localize the mobile sink and the packets have to travel more hops to reach at the sink. In such a case, the probabilities of packet loss, collision and transmission overheads also increase significantly.

To construct the *radial-canals*, at first, a set of *anchor nodes*, $Z_a = \{a_1, a_2, \ldots, a_{16}\}$, is selected starting from the right-bottom half of the main diagonal keeping $2r$ (or somewhat less) distance interval along the periphery of the network, as shown in Fig. 2(c),(d). When length of an edge is not exactly multiple of $2r$, we measure total distance along the perimeter equal to $2r$ for selecting the next anchor node. Then, we draw reference lines from each of the *anchor nodes* j, located at (x_j, y_j), to the center of the network, as follows,

$$y = \frac{y_j - v}{x_j - u}\, x, \quad 1 \leq j \leq |Z_a|. \tag{3}$$

Now, for each of the reference lines, we construct a *radial-canal* backbone by choosing nodes (i.e., $b_1, b_2, \ldots$) every after r (or somewhat less) distance, as shown in Fig. 2(c),(d). The central controller selects the backbone nodes on a *radial-canal* maintaining the property stated in Eq. 3 and minimum energy threshold (E_{th}), i.e., $E_{res} \geq E_{th}$. The selection process of backbone nodes, Z_b (i.e., $b_1, b_2, b_3, \ldots$), on *radial-canals* starts from an *anchor node* and continues until one of the *ring-canal* nodes, Z_c (i.e., c_1 to c_6), is reached, as shown in Fig. 2(c). Thus, the *ring-canal*, *anchor* and *radial-canal* nodes altogether form a connected *Starfish routing backbone* for the network, as shown in Fig. 2(d). All source sensor nodes send their sensed data toward the sink node using this backbone. Furthermore, this development facilitates 1-hop availability of at least one backbone node from any source node within the network. What follows next, we investigate the construction of an improved *Starfish routing backbone* that can further enhance the network lifetime and decrease the end-to-end packet delivery delay.

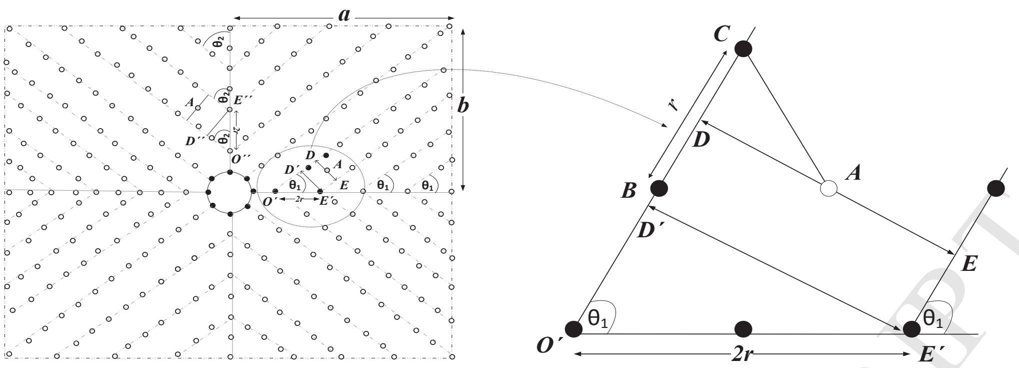
3.4. Improved Starfish routing backbone

The main philosophy of the improved backbone structure is to avoid the convergence of all *radial-canals* onto the central *ring canal*. Therefore, the construction procedure of *ring-canal* for the improved backbone remains the same as it is described in subsection 3.2. The *radial-canals* in this improved structure are parallel to the principal-diagonals of the network.

To construct the *radial-canals* of the *improved Starfish routing backbone*, at first, we draw the principal-axes and the principal-diagonals of the network passing through the network center. Now, for each of the reference axes and diagonals, we construct a *radial-canal* by choosing nodes every after r (or somewhat less) distance from network edge upto one of the nodes on the central *ring-canal*. Now, for the first *anchor* node on the principal axes just outside the *ring-canal*, we construct *radial-canals* parallel to both the principal diagonals toward the edge of the network, as shown in Fig. 3(a). Similarly, for the next *anchor* node located on the principal axes at approximately $2r$ distance from the previous one, we construct the remaining *radial-canals*. This procedure repeats for all other principal axes to form the complete *improved Starfish routing backbone* in the network.

Lemma 1. *"The Starfish routing backbone guarantees that every source sensor node in the network gets single-hop access to at least one node on the backbone, given that the principal diagonals of the network don't produce vertical angle greater than* 120° *at network center."*

Proof. Following the principle of constructing *Starfish routing backbone* described in Section 3.2 and 3.3, all nodes in the network get guaranteed single-hop access to at least one of the backbone nodes since the farthest distance between two *anchor-nodes* at the network edge is kept equal to $2r$, and thus it is trivially true.



(a) Improved Starfish routing backbone (b) Farthest source from a backbone node

Figure 3: Improved Starfish routing backbone and a special case

In the case of *improved Starfish routing backbone*, the *radial-canals* stem out from the backbone nodes on the principal-axes located every after $2r$ intervals. The distance between two consecutive parallel *radial-canals* depends on their angles incident on the principal-axes. We prove here that, if the principal-diagonals of a network don't produce vertical angles greater than 120° at network center then all nodes will have access to at least one backbone node irrespective of their positions.

Suppose a source A is located on bisection-perpendicular line drawn from the middle point of two consecutive backbone nodes B and C on a *radial-canal*, as shown in Fig. 3(b). The node A will be at the farthest position from any backbone node when it is in the middle of the bisection-perpendicular line in between two parallel *radial-canals*. Therefore, proving that the node A is guaranteed to get access of at least one backbone node is enough and sufficient condition for the above Lemma. In such a scenario, as depicted in Fig. 3(b), the right-angle triangle $\triangle ADC$ satisfies,

$$AC^2 = AD^2 + CD^2. \tag{4}$$

Since the distance between two consecutive backbone nodes B and C on a *radial-canal* is r, and the source node A must offer guaranteed access to the *radial-canal* backbone node C; putting $CD = r/2$ and $AC = r$ in Eq. 4, we obtain the maximum allowable value of $AD = \frac{\sqrt{3}}{2} \times r$, *i.e.*, $DE = \sqrt{3} \times r$.

Now, let us calculate the value of DE and determine whether the above condition satisfies or not. Note that the parallel *radial-canals* produce the same incident angle at the network center and subsequent points on the corresponding principal-axes. We assume a line $D'E'$ parallel to DE, then the right-angle triangles $\triangle\ O'D'E'$ and $\triangle\ O''D''E''$ support,

$$D'E' = DE = 2r \times sin\theta_1 \quad \text{and} \quad D''E'' = 2r \times sin\theta_2, \tag{5}$$

respectively, where, for all values of $\theta_1, \theta_2 \leq 60^\circ$, the value of DE (or $D''E''$) maintains the required condition, $DE \leq \sqrt{3} \times r$. That is, the maximum allowable vertical angle produced by principal-diagonals at network center is $60^\circ \times 2 = 120^\circ$. ■

3.5. *Updating the location of the mobile sink*

The nodes on the proposed *Starfish routing backbone* structure maintains an up-to-date position of the mobile sink. Since the backbone is constructed to be accessed from any location with 1-hop distance within the network, the mobile sink can update its position instantly to the *Starfish routing backbone*. The sink periodically broadcasts its location and as soon as one of the backbone nodes of *Starfish routing backbone* becomes aware of the change of sink location, it shares further to inform the updated sink location to all other backbone nodes over *ring-* and *radial-canals*. Since the backbone nodes are periodically updated with the current sink location, it reduces the overhead of routing path creation and can deliver sensed data immediately over the backbone nodes.

4. Analysis for End-to-End Delay in Starfish Routing

In this section, we carry out a probabilistic analysis for quantifying end-to-end packet delivery delay from source nodes to the mobile sink through *ring-* and *radial-canal* nodes on the *Starfish routing backbone*. In the state-of-the-art-works, theoretical models are developed for analyzing average end-to-end delay where only hop-distance between source to the mobile sink is considered. But due to intrinsic characteristic of wireless sensor network, end-to-end delay of a packet greatly varies not only on the hop-distance but also on the number of retransmission(s) attempted at each hop. In this section, a Markov Chain based theoretical model for end-to-end delay of a packet is developed considering both the above parameters.

In the Markov model, shown in Fig. 4, the state I is defined as an idle state, where the node has no data to transmit. Let S_h^z represents a state of packet located at h^{th}-hop distance from the sink and z^{th}-transmission or retransmission attempt, where $h \in \{1, 2, \ldots, H\}$ and $z \in \{0, 1, 2, \ldots, k\}$. That is, a packet is dropped at a given hop if all k-number of retransmission attempts are failed. When the packet is successfully received by the sink, it is destined at state S_0 in the model.

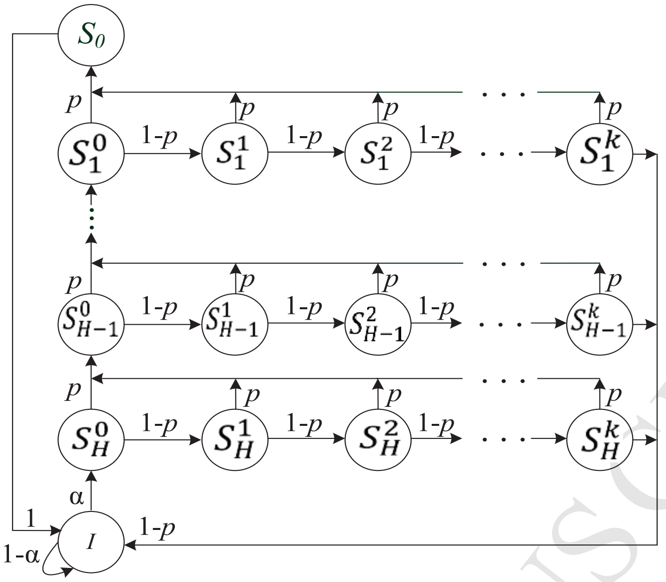


Figure 4: Markov chain model for multihop data delivery with retransmissions

Given that the packet generation rate, σ, at each source node follows Poisson distribution, the probability that one packet will arrive during a time duration t is expressed as,

$$\alpha = (\sigma t)\, e^{-\sigma t}. \tag{6}$$

The success probability (p) of a transmission attempt is binomially distributed and it is calculated as,

$$p = m\alpha\, (1-\alpha)^{m-1}\, (1-e), \tag{7}$$

where, m is the number of nodes willing to transmit in the neighborhood, and e is the probability that a packet contains one or more bit errors [37, 38].

Each state in Markov Chain model, as depicted in Fig. 4, belongs to transition probabilities ρ and altogether it produces state distribution vector **(s)** as stated in Eq. 8-10.

$$\mathbf{s} = [\ \rho_I \quad \overbrace{\rho_H^0\ \ \rho_H^1\ \ \rho_H^2 \ldots\ \ \rho_H^k} \quad \ldots \quad \overbrace{\rho_1^0\ \ \rho_1^1\ \ \rho_1^2\ \ \ldots\ \rho_1^k} \quad \rho_0]^{'}, \tag{8}$$

$$P\,\mathbf{s} = s, \tag{9}$$

$$\sum \mathbf{s} = 1. \tag{10}$$

The value of distribution vector can be found by solving Eq. 9-10 and for $H = 3$ and $z = 2$, the state distribution vector at equilibrium is represented as in Eq. 11, where, $\gamma = [1 + (1-p) + (1-p)^2]$.

$$\mathbf{s} = \frac{1}{1+\alpha\gamma+\alpha p\gamma^2+\alpha p^2\gamma^3+\alpha(p\gamma)^3}\begin{bmatrix} 1 \\ \alpha \\ \alpha(1-p) \\ \alpha(1-p)^2 \\ \alpha p\gamma \\ \alpha p\gamma(1-p) \\ \alpha p\gamma(1-p)^2 \\ \alpha(p\gamma)^2 \\ \alpha(p\gamma)^2(1-p) \\ \alpha(p\gamma)^2(1-p)^2 \\ \alpha(p\gamma)^3 \end{bmatrix} \tag{11}$$

Therefore, we can calculate the expected number of transmission- and retransmission attempts for a packet at each hop as follows,

$$\bar{z} = \sum_{z=0}^{k} z\rho_H^z. \tag{12}$$

Assuming that τ represents per packet delay due to medium access, transmission, propagation, processing and queuing delay [39], we can calculate the expected amount of delay for a packet in one hop as follows,

$$\overline{T} = \tau\,\bar{z}. \tag{13}$$

Similarly, we find the expected end-to-end delay for a packet travelling H hops as,

$$T = H \times \overline{T}. \tag{14}$$

The Fig. 5 presents comparative results of theoretical analysis and simulation experiments. The simulation experiments are performed in NS-2 for varying speeds of the mobile sink. With the increasing speed of the mobile sink in the network, average end-to-end packet delay for both theoretical and simulation results over routing-backbones decreases due to reduced average hop-distance upto

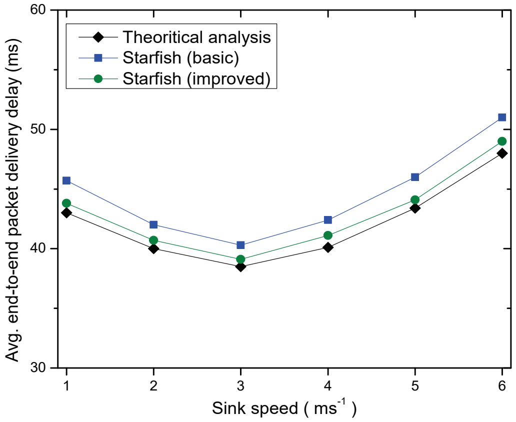


Figure 5: Comparative performance of theoretical analysis and simulation results

$3ms^{-1}$. However, longer delay requires when sink speed is high, caused by extended tracing time for localization of mobile sink by the backbone nodes. The simulation results are congruent with the theoretical experiments.

5. Performance Evaluation

In this section, we have implemented the proposed *basic Starfish*, *improved Starfish*, Ring and HexDD routing-backbone development approaches in NS-2 [25], a discrete event network simulator and compared their performances.

5.1. Simulation Environment

We have considered a WSN of $400 \times 300m^2$ area, where 500 nodes are deployed randomly with uniform distribution. The transmission range (r) of each sensor is set at $90m$; the constant bit rate traffic model is used under UDP for data transmission with a packet size of 512 bytes considering $512Kbps$ of channel bandwidth and shadowing propagation loss model. For the mobile sink in the network, we have used the random way point mobility model and all other sensor nodes are kept at stationary mode. The simulation parameters are summarized in Table 2.

5.2. Performance Metrics

The efficiency of the proposed protocol has been demonstrated by using the standard performance metrics that are described as follows.

Table 2: Simulation parameters

Parameters	**Value**
Area of the network	$400 \times 300\ m^2$
Type of node deployment	Uniformly random
Number of nodes	500
Transmission range	$90m$
Wireless Channel	WirelessPhy/802.15.4
Data packet size	512 $Bytes$
Bandwidth	512 $Kbps$
Propagation model	Shadowing loss model
Application type	Event-driven
Sink mobility model	Random way point
Initial energy of a sensor node	$6J$
Tx power	$0.023W$
Rx power	$0.018W$
Idle power	$0.037mW$
Sleeping power	$0.003mW$
Simulation time	1 hour

- *Average throughput* is measured as the number of data bytes successfully received by the sink per unit time. The higher value represents better performance.

- *Average end-to-end packet delivery delay* is the average time difference between the packet reception time at the sink and packet generation time at source. Lower value indicates improved performance.

- *Packet delivery ratio* is the ratio of the number of received packets at the sink to the generated packets by the source nodes. The higher value represents better performance.

- *Standard deviation (η) of residual energy* is the the average dispersion among the residual energy levels on backbone nodes (Z) and can be calculated as follows,

$$\eta = \sqrt{\frac{1}{|Z|} \sum_{z=1}^{|Z|} (E_{res}(z) - \mu)^2}, \tag{15}$$

where, $E_{res}(z)$ is the node z's residual energy and the mean residual energy of all backbone nodes is indicated by μ. It specifies the distribution of the energy consumption among the backbone sensors. The η value is expected to be small cause it indicates better ability of the *Starfish routing backbone* to balance energy consumption.

- *Network lifetime* is calculated from the deployment time of the network to the time at which sink becomes unreachable from a part of the network.
- *Operational overhead* is measured as the ratio of total control bytes exchanged during the whole simulation period to the total amount of data bytes delivered to the sink. A smaller value indicates better performance.

5.3. Simulation Results

The simulation experiments are run 30 times with different random seed values for an OnOff application and taken the average for each data point in the graph. The events in the network happen randomly at different places and random sources initiate flows, that remain unchanged over the simulation period. The burst description of four events considered in the simulation is tabulated in Table 3.

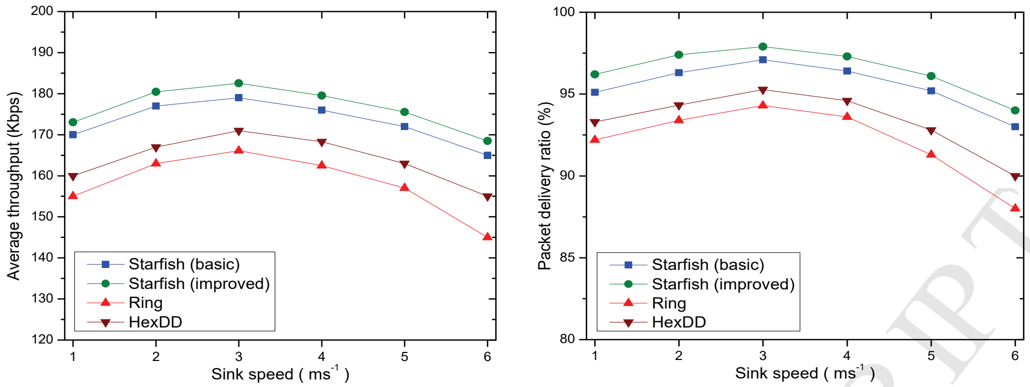
Table 3: Event and burst descriptions

	Event A	**Event B**	**Event C**	**Event D**
Burst 1	30s - 40s	90s - 100s	130s - 140s	375s - 385s
Burst 2	125s - 135s	200s - 210s	380s - 390s	565s - 575s
Burst 3	425s - 435s	660s - 670s	740s - 750s	760s - 770s

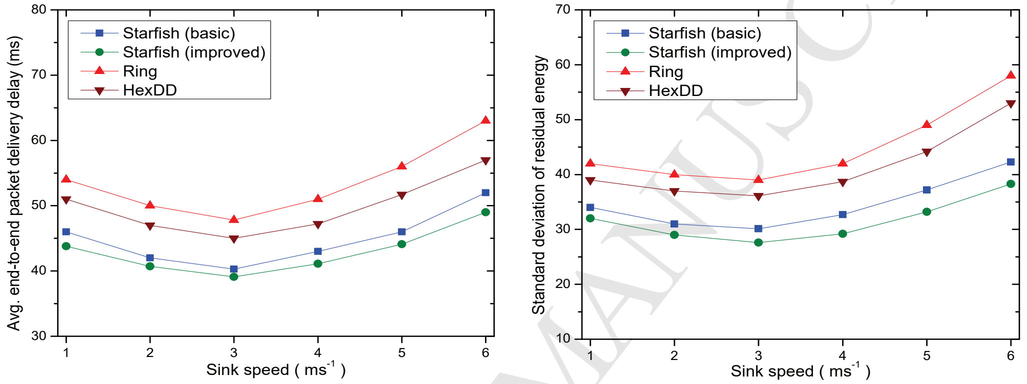
5.3.1. Impacts of varying speeds of the mobile sink

We have evaluated the performances of the studied protocols for varying sink speeds from $1ms^{-1} \sim 6ms^{-1}$. In this experiment, the network size is fixed at $400 \times 300\ m^2$, transmission range of sensor nodes is set at $90m$ and *ring-canal* control variable, $\phi = 1.0$.

The results depict that *average throughput* steadily increases with the sink speed upto $3ms^{-1}$ in all the studied protocols, as shown in Fig. 6(a). But for higher speeds of the sink, *average throughput* decreases sharply due to faster changes of routing path caused by sink mobility. The average throughput for *Starfish routing backbone* is better than those of Ring and HexDD strategies because of faster data



(a) Average throughput (b) Packet delivery ratio



(c) Average end-to-end packet delivery delay (d) Standard deviation of residual energy

Figure 6: Impacts of varying speeds of the mobile sink

communication offered by spreading backbone nodes on *radial-canals*. Moreover, *improved Starfish routing backbone* delivers higher throughput than its basic one due to reduction of collisions and interferences near *ring-canal* of the network. Similarly, the proposed *Starfish routing backbone* shows the higher *packet delivery ratio (PDR)* with increasing sink speed, as illustrated in Fig. 6(b), and later the *PDR* decreases sharply with faster speeds of the sink. This performance proves the advantages of using mobile sink with moderate speed in a wireless sensor network.

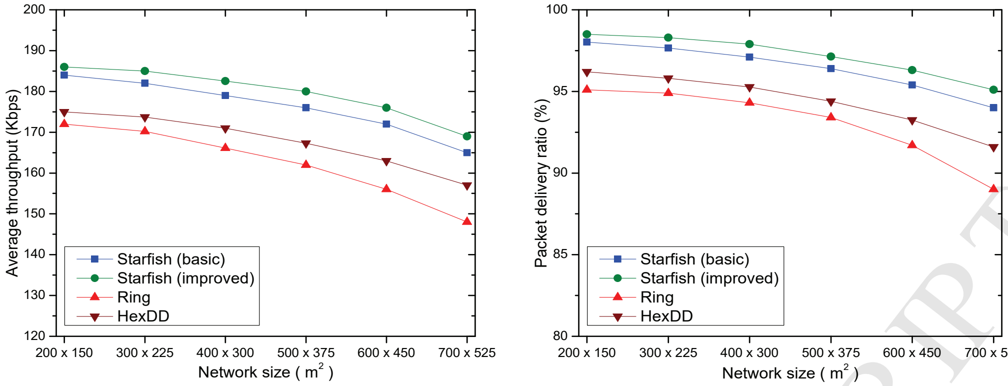
On the contrary, the *average end-to-end packet delivery delay* is decreased for all the studied backbone strategies while the sink speed is around $3ms^{-1}$, as shown in Fig. 6(c). It happens due to the fact that the sink mobility significantly reduces the average hop distance of the transmitted data packets. However, the *end-to-end delay* again increases with the increasing sink speed as the data packets had to route more hops to reach at the sink. Also, higher sink mobility causes stale sink location information, increasing the retracing time for localization. We notice that the *Starfish routing backbone* shows the *lowest data delivery delay* as it doesn't require any query for sink's fresh location comparing to ring routing in [18]. Moreover, rather than three principal-diagonals in HexDD [17], more *radial-canals* can directly transmit data to the sink, that helps our proposed *Starfish routing backbone* to minimize the *end-to-end packet delivery delay*.

Finally, for varying sink speed, the *standard deviation of residual energy* of backbone nodes for the proposed *Starfish routing backbone* is the lowest comparing to other studied protocols, as shown in Fig. 6(d). This is caused due to distributing routing loads to many backbone nodes. The deviation decreases in all the studied protocols because sink mobility provides globally less energy consumption and thus it increases network lifetime for moderate sink speed. But the deviations start to increase when the sink speed exceeds $3ms^{-1}$ due to excessive energy consumption for propagating extra messages to retrace the mobile sink and to transport data packets over longer hop paths.

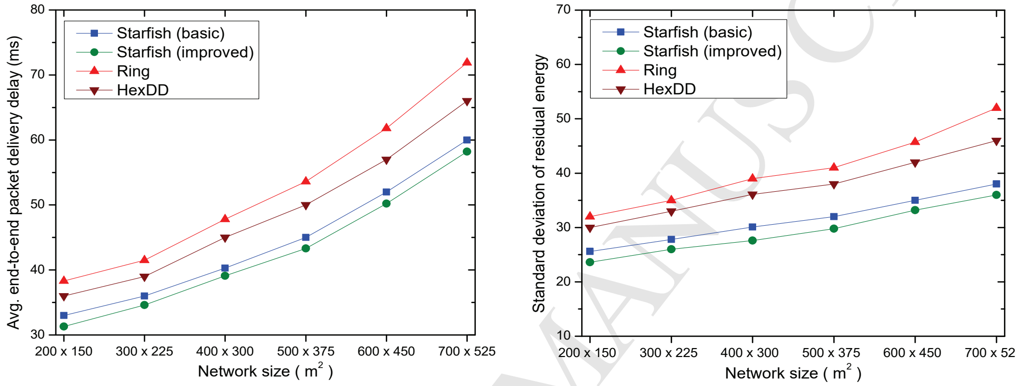
From the above discussion, it is observed that neither very slow nor very high speed mobility of the sink is beneficial, rather a moderate speed improves network performances for all studied backbone strategies. However, *Starfish routing backbone* outperforms over HexDD and Ring backbones due to fair distribution of data traffic and energy consumption over backbone nodes within the network.

5.3.2. Impacts of varying size of networks

The sink speed is not the only parameter affecting the performances of WSN routing backbones. The network size, in terms of network length and width, also affects the scalability and efficiency of *Starfish routing backbone* significantly. It happens due to the fact that the density of the network or traffic load depends on the network size. We have evaluated the performances of the studied protocols for varying size of networks from $200 \times 150m^2 \sim 700 \times 525m^2$, while a fixed number of 500 sensor nodes are deployed randomly. In this experiment, the sink speed is fixed at $3ms^{-1}$, transmission range of sensor nodes is set at $90m$ and ring-canal control variable, $\phi = 1.0$. The graphs of Fig. 7(a) illustrate that the *average throughput* steadily decreases in all the studied protocols. This happens because a fixed number of sensor nodes are deployed in increasing size of networks, that trivially reduces the probability of event notification by source nodes in the network. In case of *Starfish routing backbone*, the *average throughput* is higher compared to Ring and HexDD backbone-strategies because the premier



(a) Average throughput (b) Packet delivery ratio

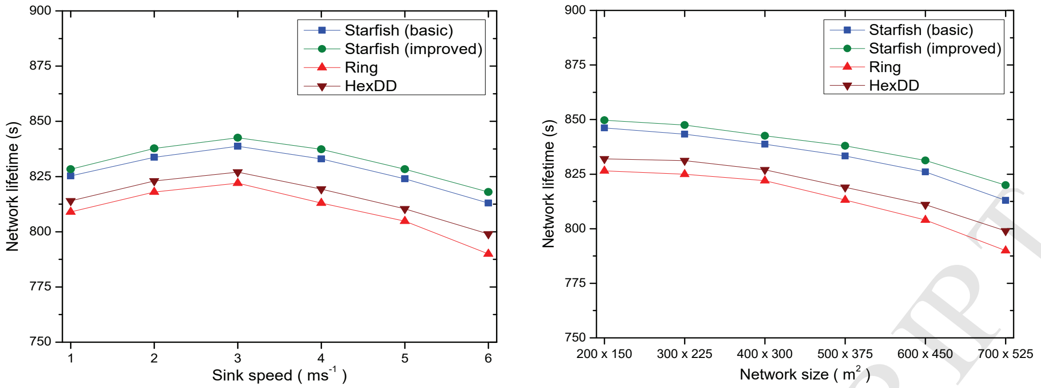


(c) Average end-to-end packet delivery delay (d) Standard deviation of residual energy

Figure 7: Impacts of varying size of networks

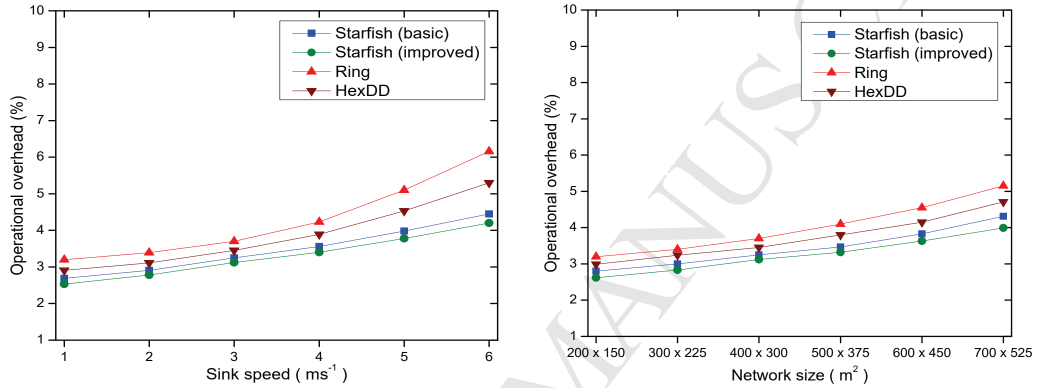
ensures guaranteed single-hop access to the backbone nodes. Similarly, the proposed *Starfish routing backbone* shows the decreasing *packet delivery ratio (PDR)* with increasing network size, as shown in Fig. 7(b). The higher *PDR* performance proves the suitability of *Starfish routing backbone* for large networks.

On the other hand, *average end-to-end packet delivery delay* is increased linearly for all the studied backbone strategies with increasing size of networks, as shown in Fig. 7(c). This happens due to increasing average hop distance between source to the sink. Besides, it is noticed that the *Starfish routing backbone* requires the lowest *end-to-end packet delivery delay* compared to other studied backbones because of guaranteed single-hop access to the backbone nodes and avoiding retracing the mobile sink in the network. This proves the suitability of *Starfish routing backbone* for real-time WSN applications. Similarly, the *standard deviation*



(a) Network lifetime

(b) Network lifetime



(c) Operational overhead

(d) Operational overhead

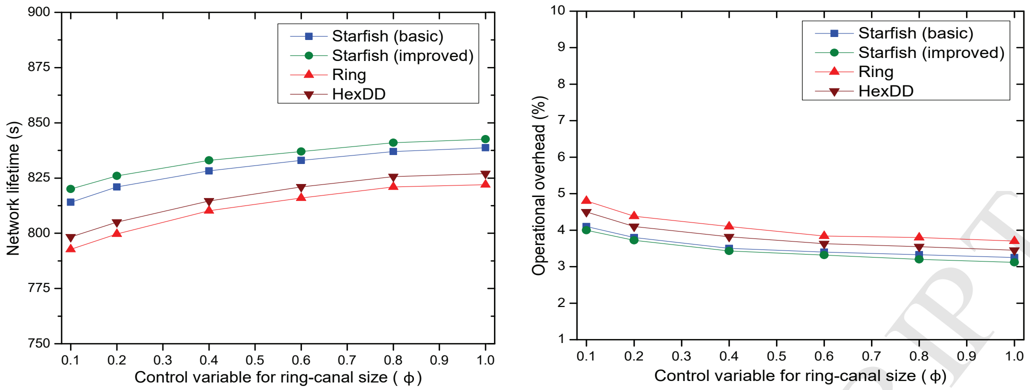
Figure 8: Effects on network lifetime and operational overhead

of residual energy for all studied backbones increases monotonically with growing size of networks, as shown in Fig. 7(d). This happens because of spreading backbone nodes on *radial-canals* within the network.

We can conclude the above results and discussions that our policy of spreading routing loads over nodes from different areas of the network helps the *Starfish routing backbone* to achieve higher level of scalability compared to the studied approaches.

5.3.3. *Effects on network lifetime and operational overhead*

The efficiency of routing backbones in WSN applications is measured on how long the *network lifetime* remains for data delivery and how much *operational overhead* requires for successful delivery of data to the sink. In these experiments,



(a) Network lifetime (b) Operational overhead

Figure 9: Impacts of varying values of ring-canal control variable, ϕ

we have set the simulation parameters for varying sink speeds and different size of networks, respectively, as similar as described in the corresponding subsections 5.3.1 and 5.3.2, to investigate the effects on *network lifetime* and *operational overhead* of the studied routing backbones.

The results illustrate that the *network lifetime* increases steadily with the sink speed upto $3ms^{-1}$ in all the studied protocols, as shown in Fig. 8(a). But for higher speeds of the sink, *network lifetime* decreases sharply due to notifying the mobile-sink location more frequently to all other backbone nodes and thus increases energy consumption than that of moderate sink speeds. The *network lifetime* for *Starfish routing backbone* is better than those of Ring and HexDD strategies because of avoiding unnecessary broadcasting for sink location updating through sensor nodes. The graphs of Fig. 8(b) depict that the *network lifetime* steadily decreases in all the studied protocols with increasing size of networks. This happens because more hops are required to deliver data packets for larger network and thus backbone nodes on the *ring*- and *radial-canals* consume more energy than that of smaller networks.

The *operational overhead* is the other metric to measure the effectiveness of the *routing-backbone* strategies. For varying sink speeds, the *operational overhead* of the proposed *Starfish routing backbone* is the lowest comparing to other studied protocols, as shown in Fig. 6(c). This is caused due to *preformed routing-backbone* with *ring*- and *radial-canals* and *guaranteed single-hop* access to the backbone. The *operational overhead* steadily increase in all the studied protocols with increasing size of networks. This happens because more control packets are transmitted for data delivery in a large network.

The experimental results substantiate the efficiency of *Starfish routing backbone* over HexDD and Ring backbones to achieve extended network lifetime for nominal operational overhead.

5.3.4. *Impacts of varying ring-canal sizes*

The efficiency of *Starfish routing backbone* greatly depends on the *ring-canal* size that is maintained by the control variable, ϕ. To investigate the effect of varying size of the *ring-canal*, we have varied the value of control variable, ϕ, between 0.1 and 1.0. The Fig. 9 shows the performance for varying *ring-canal* size while the network size, sink speed, transmission range are set at $400 \times 300\ m^2$, $3ms^{-1}$ and $90m$, respectively. The graphs in Fig. 9(a) illustrate that the *network lifetime* increases steadily as the growing values of control variable since the *radial-canals* converge to a number of *ring-canal* backbone nodes instead of a single node. It reduces the interference, collisions among the transmission from sensor nodes and thus reduces energy wastages at network center. For the similar reason, the *operational overhead* of the proposed *Starfish routing backbone* monotonically decreases with the growing values of ϕ, as shown in Fig. 9(b).

The above results signify that the *data delivery performance* and *network lifetime* improvements are influenced by the *ring-canal* size. The larger value of the *ring-canal* size improves the performances of *Starfish routing backbone* in the network.

6. Conclusion

This work investigated the problem of developing a *routing backbone* for WSNs so that the *end-to-end data delivery delay* is reduced, *network throughput* and *lifetime* can be extended. The distributed backbone-nodes over *ring-* and *radial-canals* of our proposed *Starfish routing backbone* significantly contributed to increase the *network performances* as well as *network lifetime*. The dynamic scalability of the *ring-canal* size and the number of *radial-canals* based on the *transmission range* of sensor nodes and the size of *network area* further helped the proposed *Starfish routing backbone* to outperform over the existing leading works in the literature. The experimental results, carried out in NS-2, depicted that the proposed *Starfish routing backbone* achieved as high as 13.1% and 7.4% improvements in terms of *end-to-end delay* and *throughput*, respectively, compared to HexDD routing backbone.

Determining the optimal radius of the *ring-canal* through mathematical analysis would be an interesting research problem for future study. Moreover, a suitable distributed algorithm would be developed to increase the scalability of the proposed *Starfish routing backbone* in the network.

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References

[1] Abu Zafar Abbasi, Noman Islam, Zubair Ahmed Shaikh, et al. A review of wireless sensors and networks' applications in agriculture. *Computer Standards & Interfaces*, 36(2):263–270, 2014.

[2] Bushra Rashid and Mubashir Husain Rehmani. Applications of wireless sensor networks for urban areas: A survey. *Journal of Network and Computer Applications*, 60:192–219, 2016.

[3] Ishfaq Ahmad, Khalil Shah, and Saif Ullah. Military applications using wireless sensor networks: A survey. *Int. J. Eng. Sci*, 6:7039–7043, 2016.

[4] Sajeeb Saha, Md Ahsan Habib, and Md Abdur Razzaque. Compute intensive code offloading in mobile device cloud. In *Region 10 Conference (TENCON), 2016 IEEE*, pages 436–440. IEEE, 2016.

[5] Sajeeb Saha, Md Ahsan Habib, Tamal Adhikary, Md Abdur Razzaque, and Md Mustafizur Rahman. Tradeoff between execution speedup and reliability for compute-intensive code offloading in mobile device cloud. *Multimedia Systems*.

[6] Tamal Adhikary, Amit Kumar Das, Md Abdur Razzaque, Muhammad Enamul Hoque Chowdhury, and Shohana Parvin. Test implementation of a sensor device for measuring soil macronutrients. In *Networking Systems and Security (NSysS), 2015 International Conference on*, pages 1–8. IEEE, 2015.

[7] Md Abdur Razzaque, Choong Seon Hong, Cho Jin Woong, and Lee Jang Yeon. On enhancing event-to-sink data delivery throughput in sensor networks. In *Applications and the Internet, 2009. SAINT'09. Ninth Annual International Symposium on*, pages 85–91. IEEE, 2009.

[8] Md Mamun-Or-Rashid, Muhammad Mahbub Alam, Md Abdur Razzaque, and Choong Seon Hong. Reliable event detection and congestion avoidance in wireless sensor networks. In *International Conference on High Performance Computing and Communications*, pages 521–532. Springer, 2007.

[9] Abhimanyu Das and Debojyoti Dutta. Data acquisition in multiple-sink sensor networks. *ACM SIGMOBILE Mobile Computing and Communications Review*, 9(3):82–85, 2005.

[10] Euisin Lee, Soochang Park, Fucai Yu, and S-H Kim. Exploiting mobility for efficient data dissemination in wireless sensor networks. *Journal of communications and networks*, 11(4):337–349, 2009.

[11] Euisin Lee, Soochang Park, Fucai Yu, and Sang-Ha Kim. Communication model and protocol based on multiple static sinks for supporting mobile users in wireless sensor networks. *IEEE Transactions on Consumer Electronics*, 56(3), 2010.

[12] MA Habib and Mohammad HASAN. A performance analysis of backbone structures for static sink based starfish routing in wsn. the 4th International Conference on Networking, Systems and Security (NSysS), 2017.

[13] Majid I Khan, Wilfried N Gansterer, and Guenter Haring. Static vs. mobile sink: The influence of basic parameters on energy efficiency in wireless sensor networks. *Computer communications*, 36(9):965–978, 2013.

[14] Özgür B. Akan and Ian F. Akyildiz. Event-to-sink reliable transport in wireless sensor networks. *IEEE/ACM Trans. Netw.*, 13(5):1003–1016, October 2005.

[15] Jeong-Hun Shin, Jaesub Kim, Keuntae Park, and Daeyeon Park. Railroad: virtual infrastructure for data dissemination in wireless sensor networks. In *Proceedings of the 2nd ACM international workshop on Performance evaluation of wireless ad hoc, sensor, and ubiquitous networks*, pages 168–174. ACM, 2005.

[16] Elyes Ben Hamida and Guillaume Chelius. A line-based data dissemination protocol for wireless sensor networks with mobile sink. In *2008 IEEE International Conference on Communications*, pages 2201–2205. IEEE, 2008.

[17] Ayşegül Tüysüz Erman, Arta Dilo, and Paul Havinga. A virtual infrastructure based on honeycomb tessellation for data dissemination in multi-sink mobile wireless sensor networks. *EURASIP Journal on Wireless Communications and Networking*, 2012(1):1–27, 2012.

[18] Can Tunca, Sinan Isik, Mehmet Yunus Donmez, and Cem Ersoy. Ring routing: An energy-efficient routing protocol for wireless sensor networks with a mobile sink. volume 14, pages 1947–1960. IEEE, 2015.

[19] Ashok V Sutagundar and Sunilkumar S Manvi. Fish bone structure based data aggregation and routing in wireless sensor network: multi-agent based approach. *Telecommunication Systems*, 56(4):493–508, 2014.

[20] Ramin Yarinezhad and Amir Sarabi. Reducing delay and energy consumption in wireless sensor networks by making virtual grid infrastructure and using mobile sink. *AEU-International Journal of Electronics and Communications*, 84:144–152, 2018.

[21] Halil Yetgin, Kent Tsz Kan Cheung, Mohammed El-Hajjar, and Lajos Hanzo Hanzo. A survey of network lifetime maximization techniques in wireless sensor networks. *IEEE Communications Surveys & Tutorials*, 19(2):828–854, 2017.

[22] Chuan Zhu, Guangjie Han, and Hui Zhang. A honeycomb structure based data gathering scheme with a mobile sink for wireless sensor networks. *Peer-to-Peer Networking and Applications*, pages 1–16, 2016.

[23] John M Lawrence. *Starfish: biology and ecology of the Asteroidea*. JHU Press, 2013.

[24] Md Ahsan Habib, Sajeeb Saha, Fernaz Narin Nur, and Md Abdur Razzaque. Starfish routing for wireless sensor networks with a mobile sink. In *Region 10 Conference (TENCON), 2016 IEEE*, pages 1093–1096. IEEE, 2016.

[25] Steven M. and Floyd S. Ucb/lbnl/vint network simulator-ns (version 2). 1999.

[26] Suraj Sharma, Deepak Puthal, Sanjay Kumar Jena, Albert Y Zomaya, and Rajiv Ranjan. Rendezvous based routing protocol for wireless sensor networks with mobile sink. *The Journal of Supercomputing*, pages 1–21, 2016.

[27] Jian Zhang, Jian Tang, Tianbao Wang, and Fei Chen. Energy-efficient data-gathering rendezvous algorithms with mobile sinks for wireless sensor networks. *International Journal of Sensor Networks*, 23(4):248–257, 2017.

[28] Ahmadreza Vajdi, Gongxuan Zhang, Junlong Zhou, Tongquan Wei, Yongli Wang, and Tianshu Wang. A new path-constrained rendezvous planning approach for large-scale event-driven wireless sensor networks. *Sensors (Basel, Switzerland)*, 18(5), 2018.

[29] Dezhong Shang, Xiulian Liu, Yan Yan, Cheng Li, and Baoxian Zhang. A ring-based bidirectional routing protocol for wireless sensor network with mobile sinks. In *2016 IEEE International Conference on Communications (ICC)*, pages 1–6. IEEE, 2016.

[30] Sharm Suraj and Duppada Suresh. Vgbst: A virtual grid-based backbone structure type scheme for mobile sink based wireless sensor networks. In *Proceedings of the 2015 International Conference on Advanced Research in Computer Science Engineering & Technology (ICARCSET 2015)*, page 21. ACM, 2015.

[31] Liu, Kai Zhang, Jian Shen, Zhangjie Fu, and Nigel Linge. Glrm: An improved grid-based load-balanced routing method for wsn with single controlled mobile sink. In *2016 18th International Conference on Advanced Communication Technology (ICACT)*, pages 34–38. IEEE, 2016.

[32] Anfeng Liu, Mingfeng Huang, Ming Zhao, and Tian Wang. A smart high-speed backbone path construction approach for energy and delay optimization in wsns. *IEEE Access*, 6:13836–13854, 2018.

[33] Shima Pakdaman Tirani and Avid Avokh. On the performance of sink placement in wsns considering energy-balanced compressive sensing-based data aggregation. *Journal of Network and Computer Applications*, 107:38–55, 2018.

[34] Seung-Wan Han, In-Seon Jeong, and Seung-Ho Kang. Low latency and energy efficient routing tree for wireless sensor networks with multiple mobile sinks. *Journal of Network and Computer Applications*, 36(1):156–166, 2013.

[35] Guoqiang Mao, Barış Fidan, and Brian DO Anderson. Wireless sensor network localization techniques. *Computer networks*, 51(10):2529–2553, 2007.

[36] Fernaz Narin Nur, Selina Sharmin, Md. Ahsan Habib, Md. Abdur Razzaque, Md. Shariful Islam, Ahmad Almogren, Mohammad Mehedi Hassan, and Atif Alamri. Collaborative neighbor discovery in directional wireless sensor networks: algorithm and analysis. *EURASIP Journal on Wireless Communications and Networking*, 2017, 2017.

[37] Shu Lin, Daniel J Costello, and Michael J Miller. Automatic-repeat-request error-control schemes. *IEEE Communications magazine*, 22(12):5–17, 1984.

[38] Fernaz Narin Nur, Selina Sharmin, Md Abdur Razzaque, Md Shariful Islam, and Mohammad Mehedi Hassan. A low duty cycle mac protocol for directional wireless sensor networks. *Wireless Personal Communications*, 96(4):5035–5059, 2017.

[39] Jean Walrand and Pravin Pratap Varaiya. *High-performance communication networks*. Morgan Kaufmann, 2000.

Biography of Authors

Md. Ahsan Habib received his B.Sc. and M.Sc. degrees from Islamic University of Technology, Bangladesh in 2003 and 2012, respectively. Currently, he is a PhD Student in the Department of Computer Science and Engineering, University of Dhaka, Bangladesh. He is serving as an Associate Professor in the Department of Information and Communication Technology in Mawlana Bhashani Science and Technology University, Bangladesh. His research interest incudes wireless sensor network, routing protocols, mobile cloud computing, internet of things, bioinformatics etc. He is a member of IEEE Computer Society, ACM, IEB, ISOC and Lions Club International.

Sajeeb Saha is a PhD student of the Department of Computer Science and Engineering, University of Dhaka, Bangladesh. He received his B.Sc. and M.Sc. degrees from the University of Dhaka, Bangladesh in 2007 and 2009, respectively. Currently he is in study leave from the Department of Computer Science and Engineering at Jagannath University, Dhaka, Bangladesh where he works as an Assistant Professor. His research interests include Mobile Cloud Computing, Internet of Things, Energy Optimization and Congestion Control Mechanisms.

Md. Abdur Razzaque received his B.S. and M.S. degrees from the University of Dhaka, Bangladesh in 1997 and 1999, respectively. He obtained his PhD degree in Wireless Networking from the Department of the Computer Engineering, School of Electronics and Information, Kyung Hee University, South Korea in 2009. He was a research professor, in the same university during 2010-2011. He is now working as a Professor in the Department of Computer Science and Engineering, University of Dhaka, Bangladesh. He is the group leader of Green Networking Research Group (http://gnr.cse.univdhaka.edu) of the same department. His research interest is in the area of modeling, analysis and optimization of wireless networking protocols and architectures, Wireless Sensor Networks, Body Sensor Networks, Cooperative Communications, Sensor Data Clouds, Internet of Things, Cognitive Radio Networks, etc. He has published a good number of research papers in international conferences and journals. He is an editorial board member of International Journal of Distributed Sensor Networks, TPC member of IEEE HPCC 2013-2015, ICOIN 2010-2015, ADM 2014, NSysS 2015. He is a senior member of IEEE, member of IEEE Communications Society, IEEE Computer Society, Internet Society (ISOC), Pacific Telecommunications Council (PTC) and KIPS.

Md. Mamun-Or-Rashid received his B.S. and M.S. degrees from the University of Dhaka, Bangladesh in 1998 and 1999, respectively. He obtained his PhD degree in Wireless Networking from the Department of the Computer Engineering, School of Electronics and Information, Kyung Hee University, South Korea in 2008. He was a postdoctoral fellow in the same university during 2008-2009. He is now working as a Professor in the Department of Computer Science and Engineering, University of Dhaka, Bangladesh. His research interest includes modeling, analysis and optimization of wireless networking protocols and architectures, wireless sensor networks, wireless mesh networks etc. He has published a good number of research papers in international conferences and journals.

Giancarlo Fortino is currently a Professor of Computer Engineering (since 2006) at the Dept. of Informatics, Modeling, Electronics and Systems (DIMES) of the University of Calabria (Unical), Rende (CS), Italy. He holds the "Italian National Habilitation" for Full Professorship. He has been a visiting researcher at the International Computer Science Institute, Berkeley (CA), USA, in 1997 and 1999, and visiting professor at Queensland Univ. of Technology, Brisbane, Australia, in 2009. He was nominated Guest Professor in Computer Engineering of Wuhan Univ. of Technology (WUT) on April, 18 2012. His research interests include distributed computing, wireless sensor networks, software agents, cloud computing, Internet of Things systems. He authored over 230 publications in journals, conferences and books. He is the founding editor of the Springer Book Series on Internet of Things: Technology, Communications and Computing and serves in the editorial board of IEEE Transactions on Affective Computing, Journal of Networks and Computer Applications, Engineering Applications of Artificial Intelligence, Information Fusion, Multi Agent and GRID Systems, etc. He is co-founder and CEO of SenSysCal S.r.l., a spinoff of Unical, focused on innovative sensor-based systems for e-health and demotics. He is IEEE Senior member.

Mohammad Mehedi Hassan (M'12) is currently an Associate Professor of Information Systems Department in the College of Computer and Information Sciences (CCIS), King Saud University (KSU), Riyadh, Kingdom of Saudi Arabia. He received his Ph.D. degree in Computer Engineering from Kyung Hee University, South Korea in February 2011. He received Best Paper Award from CloudComp conference at China in 2014. He also received Excellence in Research Award from CCIS, KSU in 2015 and 2016 respectively. He has published over 100+ research papers in the ISI-Indexed journals of international repute. He has also played role of the guest editor of several international ISI-indexed journals such as IEEE IoT Journal, Future Generation Computer Systems etc. He is currently an Associate Editor of IEEE Access Journal. His research areas of interest are cloud federation, multimedia cloud, sensor-cloud, Internet of things, Big data, mobile cloud, sensor network, publish/subscribe system and recommender system. He is a member of IEEE.