# On the Elliptical Ring-canal of Starfish Routing

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***Abstract*—Forming routing backbones in sensor networks are advantageous to minimize end-to-end latency and to maximize data throughput for real-time data collection. In the literature, *Starfish routing backbone* consists of a central ring-canal and few radial-canals that guarantees single hop access to one of the backbone nodes from any source node. The network performances and lifetime extension greatly depend on the optimal size of the ring-canal in the network. However, existing Starfish routing backbone develops circular ring-canal irrespective of square-shaped or rectangle-shaped network area. Therefore, in this paper, we propose an optimal ellipse as the central ring-canal on the Starfish routing backbone. The major-radius and minor-radius of the optimal ellipse are determined based on sensor's transmission range and network area. Later, we conduct simulation experiments to evaluate end-to-end latency and network lifetime and compare with state-of-the-art-works. The results show as high as 20% minimizing on end-to-end latency and as high as 10% improvement on network lifetime for real-time data collection in sensor networks.**

***Keywords: Sensor network, Starfish routing backbone, Optimal ring-canal, end-to-end latency and network lifetime.***

## I. Introduction

Backbone based routing protocols are effective to achieve significant benefits for real-time data collection in sensor networks. To achieve higher scalability and improved network performances, different backbone topologies, i.e., Ring [1], Fishbone [2], HexDD [3] or Starfish-like [4]- [8] are proposed in the state-of-the-art-works. Among them Starfish routing (SFR) backbone constructs backbone structures with a central *ring-canal* and few *radial-canals* motivating from the water vascular system of a starfish [9]. In the network, radial-canals are rayed out from the ring-canal to periphery of the network, as shown in Fig. 1. The efficiency of Starfish routing backbone greatly depends on the size of the central ring-canal in the network.

In the existing works, the construction of Starfish routing (SFR) backbones can be distinguished based on their ring-canal size. The primitive SFR-backbones [5]- [6] contain a central circular ring-canal those radius are equivalent to sensor's transmission range, as shown in Fig. 1(a) and Fig. 1(b). Since all the radial-canals converge to the central ring-canal, they suffer from more congestion, interference, forming hot-spot zone near the ring-canal. To mitigate this issue, an optimal size of circular ring-canal is proposed in [7]- [8], as shown in Fig. 1(c) and Fig. 1(d), through an mixed integer linear programming (MILP). The MILP model determines the optimal radius of a reference-circle to construct ring-canal in the network. In case of square area, circular ring-canal becomes a good choice. However, construction of an efficient Starfish routing backbone with an optimal elliptical ring-canal in a rectangle network is still unexplored.

Therefore, in this paper, we propose Starfish routing backbone with optimal elliptical ring-canal dynamically determined using sensor's transmission range and area of the network. It is expected significant reduction in end-to-end latency and extending network lifetime for real-time data collection with a mobile sink. The simulation results, evaluated in Network Simulator (NS-2), shows the effectiveness of Starfish routing backbone with an elliptical ring-canal in terms of end-to-end latency and network lifetime compared to the state-of-the-art-works.

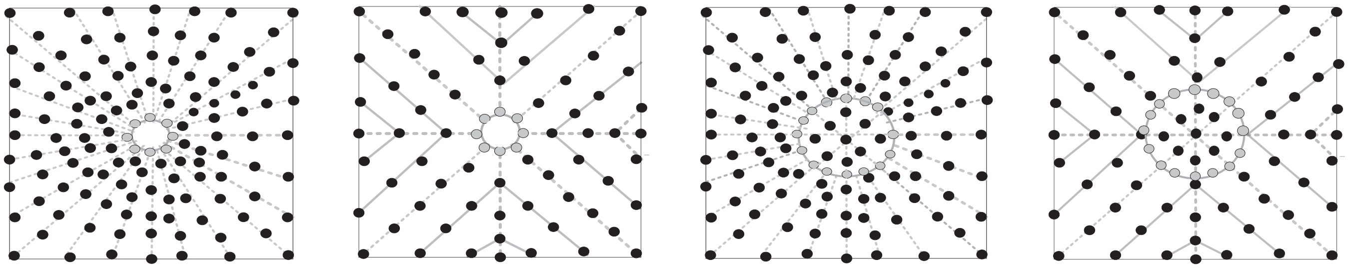
The remainder of the paper is organized as follows. Section II describes the related works followed by network model in Section III. Section IV explains the details of elliptical ring-canal construction for Starfish routing backbone in the network. Finally, we conclude the paper in Section VI.

## II. Related works

In the literatures, Starfish routing (SFR) backbone constructs its backbone topology with a central *ring-canal* and few *radial-canals* motivating from the water vascular system of a starfish [9]. In the network, the ring-canal is centrally located, and few radial-canals are rayed out from the ring-canal to periphery of the network, as shown in Fig. 1.

Based on radial-canal's construction, SFR topologies construct two variants of Starfish routing backbone, namely basic-SFR (bSFR) and improved-SFR (iSFR) backbones. In basic SFR (bSFR) backbone, all radial-canals converge directly to the central ring-canal from network periphery, as shown in Fig. 1(a) and Fig. 1(c). On the contrary, in improved-SFR (iSFR) backbone, radial-canals converge to one of the principle axes following parallel reference-line to the principle diagonals of the network, as shown in Fig. 1(b) and Fig. 1(d).

Furthermore, there are two strategies to construct the central ring-canal of a Starfish routing (SFR) backbone in the network. The primitive strategy constructs a central circular ring-canal those radius is estimated as the equivalent to sensor's transmission range [5]- [6], as shown in Fig. 1(a) and Fig. 1(b). Later, to improve the efficiency of Starfish routing backbone, optimal radius of a reference-circle for the ring-canal is determined based on sensor's transmission range and size of the network [7]- [8], as shown in Fig. 1(c) and Fig. 1(d). These strategies are explained in brief as follows.



(a) Basic SFR (bSFR) backbone (b) Improved SFR (iSFR) backbone (c) bSFR with optimal ring-canal (d) iSFR with optimal ring-canal

Fig. 1. Starfish routing (SFR) backbone structures

### A. Sensor's transmission range based ring-canal

In the primitive strategy, the ring-canal is constructed based on the transmission range of a sensor node. 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. A central ring-canal is a closed loop of nodes circularly located around the center of the wireless sensor network, as shown in Fig. 1(a) and Fig. 1(b).

The center of the ring-canal is fixed at the network center and a set of ring-canal backbone nodes is selected on a reference-circle to preserve its circular property [6]. We assume, $r$ is the transmission range of a sensor node and $(u, v)$ is the network center, then the reference-circle is estimated as follows, $(x - u)^2 + (y - v)^2 = r^2$. Now, a central controller picks a sensor node randomly on or somewhat inside reference-circle as the starting node of the ring-canal. Later, the next nodes are selected after every $r$ distance on or inside the reference-circle. This selection process of ring-canal backbone nodes continues until the starting node of the ring-canal is reached.

### B. Optimal-reference-circle based ring-canal

In the former approach of sensor's transmission range based ring-canal construction, the maximum radius of the ring-canal is bounded by sensor's transmission range irrespective of network area and all the radial-canals converge to the central ring-canal that suffer from more congestion, interference, forming hot-spot zone near the ring-canal. To mitigate this issue, optimal-reference-circle based ring-canal is proposed for SFR backbone. The key motivation for finding the optimal radius of ring-canal is to converge each radial-canal onto one ring-canal node, as shown in Fig. 1(c) and Fig. 1(d).

*1) Basic SFR with optimally circular ring-canal (bSFR-circular):* Since the backbone nodes on the ring-canal are positioned approximately every $r$ distance away, the number is measured for the central ring-canal with optimal radius $R_{opt}$ as $2\pi R_{opt}/r$. Meanwhile, the number of radial-canals of the basic Starfish routing backbone is initiated every after $2r$ distance along network periphery that is estimated as $(2\times(2a+2b))/2r$, given that the network area is $2a \times 2b$ $(a \geq b > r)$, as shown in Fig. 1(a) and Fig. 1(c). Since the key motivation for finding the optimal radius $R_{opt}$ of ring-canal is to converge each radial-canal onto one ring-canal node, it implies $2\pi R_{opt}/r \cong (2 \times (2a + 2b))/2r$. Therefore, basic Starfish routing (bSFR) backbone contains the optimal radius $R_{opt}$ of the ring-canal that is estimated as $R_{opt} \cong (a + b)/\pi$.

Now based on the optimal radius for the ring-canal, the reference-circle is estimated as follows, $(x-u)^2+(y-v)^2 = R_{opt}^2$. Now, a central controller picks a sensor node randomly on or somewhat inside reference-circle as the starting node of the ring-canal, and continues until the closed-loop ring-canal is formed.

*2) Improved SFR (iSFR) with optimally circular ring-canal:* The main philosophy of the improved backbone structure is to avoid the convergence of all radial-canals onto the central ring canal. Therefore, The radial-canals are constructed parallel to the principal-diagonals of the network. To construct the radial-canals for improved Starfish routing (iSFR) backbone, at first, we choose anchor nodes on the principal axes every after $2r$ distance, and then construct radial-canals parallel to both the principal diagonals from each anchor node toward the edge of the network, as shown in Fig. 1(b) and Fig. 1(d).

Finding the optimal radius for iSFR follows similar approach as for basic Starfish routing (bSFR) backbone except computing the number of radial-canals on the principle axes. Since anchor nodes initiate radial-canals, it determines the maximum number of radial-canals in iSFR. For a network area of $2a\times 2b$, the total number of anchor nodes can be maximum of $(2a + 2b)/2r$ on the principle axes, as shown in Fig. 1(b) and Fig. 1(d).

Since each anchor node initiates two radial-canals that are parallel to the principle diagonals, the total number of radial-canals for iSFR can be estimated as $2 \times ((2a+2b)/2r)$. Now the key motivation for finding the optimal radius $R_{opt}$ of ring-canal for iSFR is to converge each radial-canal onto the ring-canal, that implies $2\pi R_{opt}/r \cong 2\times((2a+2b)/2r)$. Therefore, iSFR backbone contains the optimal radius $R_{opt}$ for the ring-canal that is estimated as $R_{opt} \cong (a + b)/\pi$.

*3) Proposed further optimized circular ring-canal for iSFR (iSFR-circular):* Though the above formulation computes the optimal radius of the ring-canal for iSFR, as proposed in [7]-[8], the size of the ring-canal would be further optimized. In existing iSFR backbone, the total number of radial-canals are determined by the estimated anchor nodes on the principle axes. However, in a practical case, we would not expect the ring-canal be too large to converge with the radial-canals initiated from the both-end anchor nodes for both principle axes. Therefore, the total number of anchor nodes can be re-estimated as $2\times((2a-2r)+(2b-2r)/2r)$, and thus we propose the optimal radius such that $2\pi R_{opt}/r \cong 2\times((2a-2r)+(2b-2r)/2r)$, which implies further optimized radius $R^{'}_{opt}$ of the ring-canal for iSFR is as follows, $R_{opt} \cong (a+b-2r)/\pi$.

The above formulations proposed in [4]- [8] determine the optimal radius of circular ring-canal for both bSFR and iSFR, irrespective of network area is square- or rectangle-shaped. In case of square area, circular ring-canal could be a good choice that would not be equally expected or as much as appropriate for a rectangular-shaped network. Moreover, construction of optimal elliptical ring-canal in a rectangular-shaped network is still unexplored.

Therefore, in this paper, we propose Starfish routing backbone with optimal elliptical ring-canal dynamically determined using sensor's transmission range and area of the network.

## III. Network Model and Assumptions

Let us assume, a sensor network contains homogeneous-sensor nodes having transmission range, $r > 0$, that are scattered within a rectangular-network, as depicted in Fig. 2. The size of the rectangular area is assumed $2a \times 2b$, where $a$ and $b$ $(a > b > r)$ are the halves of network sides. All deployed sensor-nodes remain stationary, while the mobile-sink can travel within the network.

Motivating from the water vascular system of a starfish, we consider a *Starfish routing backbone* consists of different types of backbone nodes, i.e., ring-canal nodes, radial-canal nodes and anchor nodes. Here, each anchor node is selected along the network periphery as a closed loop or on the both principal-axes every after $2r$ distance, as shown in Fig. 2. Then each anchor node initiates to construct each radial-canal to converge at one of the ring-canal nodes of Starfish routing backbone. We assume, $Z_a$ and $Z_c$ are the set of anchor nodes and elliptical ring-canal nodes, respectively. To find optimal reference-ellipse for constructing the central ring-canal of the Starfish routing backbone.

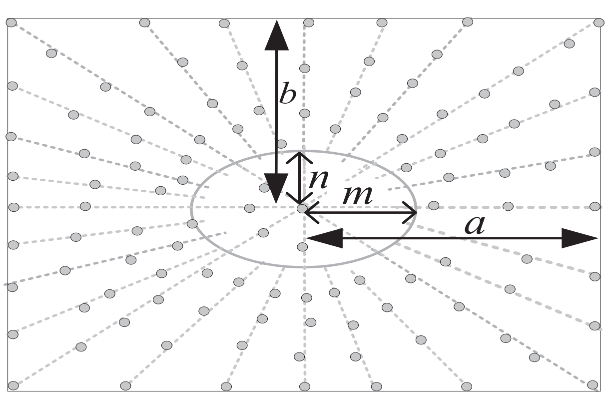



Fig. 2. Proposed SFR network model with elliptical ring-canal

## IV. Elliptical Ring-canal of Starfish Routing

The development of an efficient backbone in sensor network is not only important to minimize end-to-end latency but also to maximize network lifetime to a great extent. Therefore, we develop Starfish routing backbone for a rectangle size of network with elliptical ring-canal. Our key objective of this work is to find a reference ellipse in the network that guides to construct ring-canal based on sensor's transmission range $(r)$ and network size $(2a \times 2b)$.

### A. bSFR with optimally elliptical ring-canal (bSFR-Elliptical)

In *Starfish-backbone topology*, a set of *anchor nodes*, $Z_a$, is selected along the network periphery after every $2r$ (or somewhat less) distance. Since each anchor node initiates to construct a corresponding radial-canal, the number of *radial-canals*, $|Z_a|$, is estimated following Eq. (1).

$$|Z_a| = \frac{2\times(2a+2b)}{2r} = \frac{2\times(a+b)}{r} \tag{1}$$

From the experimental results of existing works, it is observed that *basic Starfish routing* suffers for both the extreme size of *ring-canals*, i.e., extraordinarily large and very small, in the network. Moreover, the performance of the protocol affects due to higher hop-distances, increased interference, and collision. Therefore, we find reference ellipse for the optimal ring-canal in terms of major-radius and minor-radius. We assume, $m$ and $n$ are the major-radius and minor-radius of the ellipse, respectively, that are suitably tuned by a control variable $\phi$ for varying size of networks using Eq. (2) and Eq. (3).

$$m = \phi\ a \tag{2}$$

$$n = \phi\ b \tag{3}$$

Here, $\phi$ is a control-variable for computing optimal reference-ellipse with respect to width $(a)$ and hight $(b)$ of the network. The key motivation for finding the optimal major-radius and minor-radius is to converge each radial-canal onto one backbone nodes on the elliptical ring-canal. Thus, both $m$ and $n$ should be large enough so that each radial-canal can converge to the only corresponding elliptical ring-canal of Starfish routing backbone. Since the ring-canal backbone nodes are placed on the reference-ellipse every after $r$ distance, the total number of ring-canal backbone nodes $Z_c$ depends on its perimeter $2\pi\sqrt{\left((m^2+n^2)/2\right)}$. Thus, $|Z_c|$ can be estimated as follows,

$$|Z_c| = \frac{2\pi\sqrt{\left((m^2+n^2)/2\right)}}{r} \tag{4}$$

In case of efficient converge of each radial-canal exactly onto a ring-canal backbone node, we find optimal reference-ellipse, if and only if, $|Z_c| \cong |Z_a|$. Therefore, we get,

$$\frac{2\pi\sqrt{((m^2+n^2)/2)}}{r} \cong \frac{2\times(a+b)}{r} \tag{5}$$

$$\Rightarrow (m^2 + n^2 \cong 2 \times \Big(\frac{a+b}{\pi}\Big)^2 \tag{6}$$

Now, putting the values of $m$ and $n$ (from Eq. (2) and Eq. (3)) into Eq. (6), we get,

$$\phi^2\Big(a^2 + b^2\Big) = 2\Big(\frac{a+b}{\pi}\Big)^2 \tag{7}$$

Finally, we compute the control-variable $\phi$ for determining reference-ellipse in the network as follows,

$$\phi = \frac{\sqrt{2}}{\pi}\ (a+b)\ \sqrt{\Bigg(\frac{1}{a^2+b^2}\Bigg)} \tag{8}$$

Therefore, we get the optimal reference-ellipse using Eq. (9) for the major-radius $m = \phi\ a$ and minor-radius $n = \phi\ b$ in the network.

$$\Big(\frac{x-u}{m}\Big)^2 + \Big(\frac{y-v}{n}\Big)^2 = 1 \tag{9}$$

After getting the reference-ellipse, we construct bSFR with elliptical ring-canal and radial-canals. At first step, we sketch a reference-ellipse using Eq. (9), as shown in Fig. 2. Then, the central controller selects a node on or nearby of reference-ellipse randomly. The next nodes for the elliptical ring-canal are selected after every $r$-distance on the reference-ellipse. This step continues to select nodes until a closed loop of elliptical ring-canal is constructed.

Secondly, to construct the radial-canals, we draw principal-diagonals of the network passing through the network center $(u, v)$ and select some anchor nodes along network periphery after every $2r$ (or somewhat less) distance, starting from any corner of a diagonal. For each anchor node, we assume a straight line to the network center. Then the controller selects backbone nodes on each line every after $r$ distance from a anchor node to the elliptical ring-canal. The radial-canal for each anchor node converges to one of the elliptical ring-canal backbone nodes in the center with the exception for two principal diagonals. In the case of principal-diagonals, the radial-canals pass across the network center.

### *B. iSFR with optimally elliptical ring-canal (bSFR-Elliptical)*

Finding the optimal radius for iSFR follows similar approach as for basic Starfish routing (bSFR) backbone except computing the number of radial-canals on the principle axes. Since anchor nodes initiate radial-canals, we determine the maximum number of radial-canals for iSFR, in the light of our proposed estimation described in Section II(B)(3), for a network area of $2a \times 2b$, the total number of anchor nodes can be maximum of $((2a - 2r) + (2b - 2r)/2r)$ on the principle axes. Since each anchor node initiates two radial-canals that are parallel to the principle diagonals, the total number of radial-canals for iSFR can be estimated as $2 \times ((2a - 2r) + (2b - 2r)/2r)$.

In case of efficient converge of each radial-canal onto an elliptical ring-canal backbone node, we find optimal reference-ellipse, if and only if, it follows Eq. (10).

$$\frac{2\pi\sqrt{((m^2+n^2)/2)}}{r} \cong \frac{2 \times ((2a-2r)+(2b-2r))}{r} \tag{10}$$

Now, putting the values of $m$ and $n$, we get the control-variable $\phi$ for iSFR as follows,

$$\phi = \frac{\sqrt{2}}{\pi}\ (a+b-2r)\ \sqrt{\Bigg(\frac{1}{a^2+b^2}\Bigg)} \tag{11}$$

Therefore, we get the optimal reference-ellipse using Eq. (9) for the major-radius $m = \phi\ a$ and minor-radius $n = \phi\ b$ in the network. After sketching the reference-ellipse, the central controller selects a node on or nearby of reference-ellipse randomly. The next nodes for the elliptical ring-canal are selected after every $r$-distance on the reference-ellipse. This step continues to select nodes until a closed loop of elliptical ring-canal is constructed.

On the other hand, to construct the radial-canals, we draw principle-axes and principal-diagonals of the network passing through the network center $(u, v)$ and select some anchor nodes on principle-axes after every $2r$ (or somewhat less) distance from network center. For each anchor node, we assume parallel lines to the principle-diagonals in both sides of principle-axes. Then the controller selects backbone nodes on each reference-line for radial-canals, principle-axes and principle-diagonals every after $r$ distance.

Finally, for both bSFR and iSFR, all selected backbones nodes on elliptical ring-canal and radial-canals are connected to construct Starfish routing backbone with optimal ellipse-shaped ring-canal.

## V. Performance Evaluation

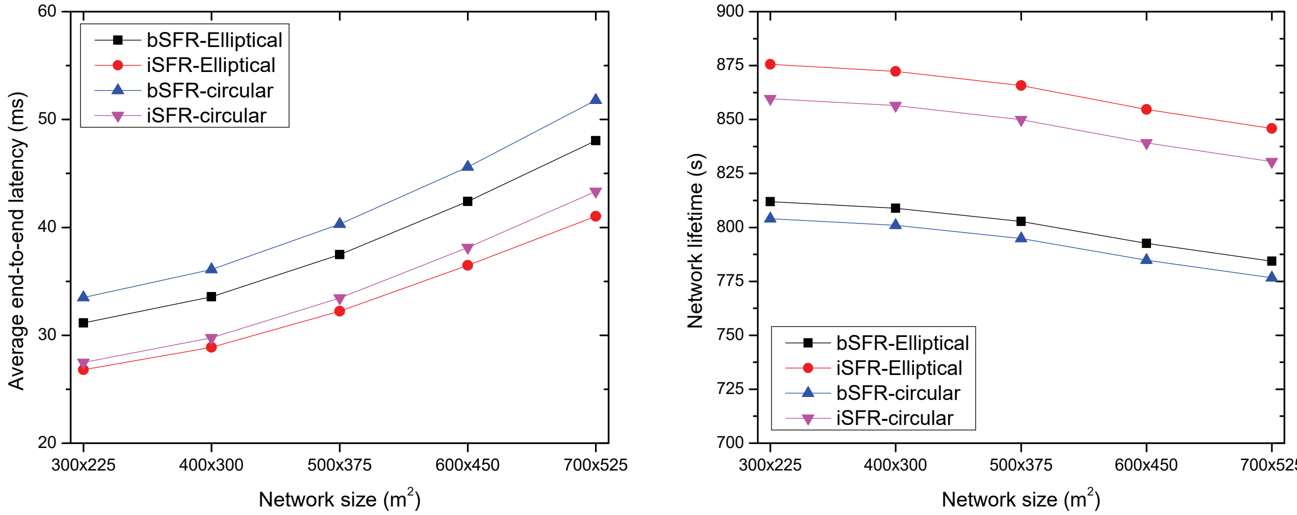
In this section, the performances of the elliptical ring-canal for both variants of Starfish routing backbones (i.e., bSFR-elliptical and iSFR-elliptical) are exhaustively evaluated in NS-2 [10] and compared with that of circularly located ring-canal (i.e., bSFR-circular and iSFR-circular) on the Starfish routing backbones.

### *A. Simulation environment*

In the experiment, 500 nodes are deployed randomly in a network, and constant bit rate is applied while transmitting data with 512-bytes packet size over 512-Kbps channel. The data points in graphs are corresponding to average results of 15 simulation runs. In the experiments, simulations are run for $1000s$.

### *B. Simulation results*

Here, the comparative performances of the proposed bSFR-elliptical and iSFR-elliptical Starfish routing backbones are compared with bSFR-circular and iSFR-circular Starfish routing backbones in terms of *end-to-end latency* and *network lifetime*. In the simulation experiments, network size is varied from $300 \times 225\ m^2$ to $700 \times 525\ m^2$.



(a) Average end-to-end latency (b) Network lifetime

Fig. 3. Impacts of varying size of networks

*1) Impacts of varying size of networks:* In the graphs, as illustrated in Fig. 3, the performances on end-to-end latency and network lifetime are shown.

It is observed that average end-to-end latency is increased for larger size of networks in all studied works, as shown in Fig. 3(a). It is obvious due to requiring more hop-distance for larger size of networks. However, Starfish routing backbones with elliptical ring-canals (i.e., bSFR-elliptical and iSFR-elliptical) outperforms over that of circular ring-canals (i.e., bSFR-circular and iSFR-circular) in the network. This happens because of the suitability of elliptical ring-canal over circular ring-canal on the Starfish routing backbones.

On the contrary, with the increasing size of networks, network lifetime gradually decreases for all studied works as illustrated in Fig. 3(b). This is because of requiring more energy expenditure for increasing hop-distance to deliver sensed data to the sink. However, elliptical ring-canal based (i.e., bSFR-elliptical and iSFR-elliptical) Starfish routing backbones outperform over circular ring-canals. This is because of choosing optimally formed elliptical ring-canal in the network, which mitigates excessive energy expenditure and to achieve efficient data delivery over the routing backbone.

These results show that the proposed elliptical ring-canal based Starfish routing backbones outperform over circular ring-canals significantly.

## VI. Conclusion

In this paper, we have investigated existing Starfish routing backbones and found that construction of effective ring-canal in a rectangular-shaped network is still unexplored. Therefore, we developed Starfish routing backbone with optimally selected elliptical ring-canal in the network. The simulation experiments show that the proposed elliptical ring-canal significantly impacts on end-to-end latency and network lifetime performances over circular ring-canal on Starfish routing backbones. The evaluation results show as high as 20% minimizing on end-to-end latency and as high as 10% improvement on network lifetime for real-time data collection in sensor networks. In future, few other network performance issues will be evaluated to evaluate the feasibility of the proposed model.

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