Performance Evaluation of Mini-sinks Mobility Using Multiple Paths in Wireless Sensor Networks

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Abstract

This paper presents a new approach based on the use of many data collectors, which we designate Mini-Sinks (MSs), instead of a single sink to collect the data in order to improve Wireless Sensor Network (WSN) performance. One or mode MS are mobile and move according to a controlled arbitrary mobility inside the sensor field in order to maintain a fully-connected network topology, collecting data within their coverage areas and forwarding it towards the single main sink. Energy Conserving Routing Protocol (ECRP), based on route diversity, is implemented in MSs and sensors in order to optimize the transmission cost of the forwarding scheme. A set of multiple routing paths between MSs and sensors is generated to distribute the global traffic over the entire network. Simulations were performed in order to validate the performance of our new approach. We compare the results obtained with those for a single static sink and mobile sink, and show that our approach can achieve better performances such as packet delivery ratio, throughput, end-to-end delay, network lifetime, residual energy, energy and routing diversity overhead.

Keywords: Wireless Sensor Network, Mini-sink Mobility, Multiple Paths, Congestion, Network Performance.

1. INTRODUCTION

The advances in micro-electro-mechanical technologies bring significant advantages to the development of low-cost sensors equipped with storage, computing and communication capabilities. Wireless Sensor Networks (WSNs) are ad hoc wireless networks that consist of a large number of small devices, known as sensors, scattered over a particular geographical area [1]. As an emerging technology, they have gained much attention in a large range of technical fields such as industrial, biological, medical, military, nuclear science, forest fire detection, air pollution monitoring etc. The lack of a predefined communication infrastructure increases the challenge in the design of communication techniques for these networks, especially in hostile environments, where it is often difficult to replace sensor batteries after deployment and where communication infrastructures are not accessible or available.

In WSNs, all sensor nodes send their data towards the central sink, which is the final recipient of the sensed information. It is typically connected to conventional computing equipment for complex processing of the accumulated readings. Each sensor is equipped with a limited amount of storage capacity and energy, and is able to communicate with its neighbours over wireless connections. Thus, the sensor energy is the main impediment to improve overall network performance. Self-configuration is mandated to give all sensors the possibility of efficiently forwarding data towards the sink for improving network performance [3].

In this paper, we evaluate network performance [2] such as Packet Delivery Ratio (PDR), Throughput, End-to-End-Delay (E_2ED_{elay}), Network Lifetime (NL), Residual Energy (RE), Energy Overhead (EO) and Routing Diversity Overhead (RDO). In a nutshell, the main contributions of this paper are as follows:

• The use of several MSs instead of a single sink, for collecting the data, in order to improve overall network performance.
• Sensors and the main sink are fixed, but MSs are mobile. The MSs move inside the sensor field according to a controlled arbitrary mobility model in order to maintain a fully-connected network topology, collecting data within their coverage areas and forwarding it towards the sink.
• Energy Conserving Routing Protocol (ECRP), based on route diversity, is implemented in MSs and sensors in order to optimize the transmission cost of forwarding [4].
• A set of multiple routing paths between MSs and sensors is generated to distribute the global traffic over the entire network. Thus, network performance can be improved significantly.

Extensive simulations have been performed in order to validate the performance of our approach. We compare the results obtained with those for a single and mobile sink [5] by taking PDR, Throughput, E_2ED_{elay}, NL, RE, EO and RDO as performance criteria. We show that our new approach can achieve better results.

The remainder of this paper is organized as follows: Section 2 outlines related work. Section 3 formulates the problem and presents our Mini-Sink mobility model. Section 4 discusses our proposed approach. Section5 presents performance metrics. Section 6 presents analysis and performance results and Section 7 concludes the paper.

2. RELATED WORK

In the past, many works have been proposed using the mobility of the sink for collecting the data. The sink mobility can be classified into mobile base station, mobile data collector and rendezvous-based taking into account the movement pattern of mobile sinks and the manner the data are collected [6]. We focus on the deployment of many mobile data collectors for decreasing the load in order to improve overall network performance.

In the mobile data collector, many mobile data collectors are used to collect the sensed data from fixed sensors. According to the sink mobility pattern, we can classify into random, predictable and controlled mobility [7]. In random mobility, mobile data collectors move along a random path inside the sensor field and implement a technique for collecting the data from fixed sensors. But random mobility does not guarantee the collection of data from all sensors and need a high delay to deliver the data. In predictable mobility, the mobile data collector moves along a predefined or a fixed path for improving network performance. In this case, all sensors should know the movement of data collectors in order to predict the forwarding time, helping to improve overall network performance. In controlled mobility, the mobility of data collectors is controlled. The approach presented in this paper is based on an arbitrary mobility of MSs for maintaining a fully-connected network, collecting the sensed data from fixed sensors not in arbitrary manner, but controlled based on ECRP.

We describe now some recent works investigating the use of mobile sinks or mobile data collectors for increasing WSN performances.

Vecchio et al. [8] propose density-based proactive techniques that do not impose any restrictions on mobility of the sink. They approach combines a probabilistic flooding and storing scheme for collecting data. Hamida et al. [9] explore recent data dissemination protocols using mobile sinks and analyze the mobility impact on energy consumption and the network lifetime. Marta et al. [10] propose an approach in which mobile sinks change their location when energy of sensors nearby mobile sinks is depleted. The new location of mobile sinks follows the path with the maximum energy of sensors for improving network lifetime. Yang et al. [11] propose the using of mobile sinks to route data towards the destination via the shortest paths. The residual energy is taking into account in the shortest paths calculation in order to maximize network lifetime and overhead. Li et al. [12] study the theoretical aspects of the uneven energy depletion phenomenon around a sink, and address the problem of energy-efficient data gathering by mobile sinks. Cuomo et al. [13] study the effects of sensor node mobility on network formation according to IEEE 802.15.4/ZigBee. They focus on single-sink and multi-sink configurations to analyze network performance as a function of the number of sinks. Vlajic et al. [14] propose the evaluation of various deployment strategies involving sink mobility in the real world in order to reduce energy consumption and propagation delay while increasing network lifetime. Maria et al. [15] propose a novel linear programming model for network lifetime maximization by determining the movement of the sink rather than minimizing the energy consumption at the nodes. Their proposed model results in a fair balancing of energy depletion among the network nodes. Luo et al. [16] propose a model that uses the mobility of the sink in such a way that the sensor nodes located in the vicinity of the sink change over time. They show that combining the mobility of the sink with routing protocols helps to balance the load and so optimizes network lifetime. Ioannis et al. [5] propose the use of random sink mobility to reduce data latency and increase WSNs lifetime, although random sink mobility is not sufficient to guarantee the collection of data from all sensors.

Our approach presented in this paper is close to [5]. One difference is that, we propose a new approach in which a set of multiple paths using ECRP between the closest MSs and sensors is generated in order to optimize the transmission cost of the forwarding scheme. The forwarding scheme is controlled based on ECRP. Such a method has the advantage of distributing the global traffic over the entire network topology.

To the best of our knowledge, there is no previous study that investigates the use of multiple paths between sensors and MSs for improving WSN performances. In this paper, we use the terms multiple paths and route diversity interchangeably.

3. PROBLEM STATEMENT AND PROPOSITION

In this section, we formulate the problem addressed in this paper and outline our Mini-Sink mobility model.

3.1 Problem Statement

As already presented in our previous work [17], the main cause of decreasing network performance in WSNs is the transmission of data from all sensor nodes towards a single sink. One of the main disadvantages of this communication model is increasing of congestion in the network. Congestion may occur in a WSN for two major reasons: 1) Due to the short wireless communication range of sensors, the sink can only communicate with a limited number of sensors, namely the sensors in the vicinity of the sink. It may happen that some sensors in the vicinity of the sink collect more data because they are aggregating the data from other sensors. Thus, congestion starts to build up on these sensors, and the residual energy in these sensors quickly becomes depleted, so are more prone to shutdown [18]. 2) Since each sensor is equipped with a limited amount of storage capacity and energy supply, at any given moment, some routing sensors fail to transmit or receive the data because the amount of data collected becomes greater than the amount of data that can be forwarded, causing the emergence of local congestion at these routing sensors, so impacting network performance.

3.2 Proposition

To address these problems, we propose that, instead of having a central sink responsible for all data collection, we introduce many data collectors, which we designate Mini Sinks (MSs). These

MSs move in the sensor field according to a controlled arbitrary mobility model in order to maintain a fully-connected network topology, collecting data within their coverage areas and forwarding it towards the sink. Thus, the overall network performance as PDR, Throughput, E_2ED_{elay}, NL, RE, EO and RDO can be improved significantly.

3.3 Network Architecture and Assumptions

Our network architecture consists of three classes of nodes:

- MSs are special nodes equipped with unlimited energy and storage capacity.
- Sensor nodes are responsible for sensing their nearby environment.
- A single sink provides a gateway to conventional computing equipment.

We assume in our new approach that:

- Sensors and MSs are deployed in an area L.
- Sensors are homogeneous and fixed.
- Each sensor maintains a list of the identities (Id) of its neighbours.
- Links between two adjacent sensor nodes are always bidirectional.
- Each sensor takes readings at a fixed rate and forwards them to the most accessible MS.
- MSs are mobile and can return to a recharging point when their energy reserves have been depleted.
- MSs are responsible for collecting the data from sensors and forwarding it towards the sink.
- A single sink is the final recipient of all the sensed data.

3.4 Mini-Sink Mobility Model

In our new approach, the MSs move according to a controlled arbitrary mobility model inside the sensor field as shown in Figure 1.

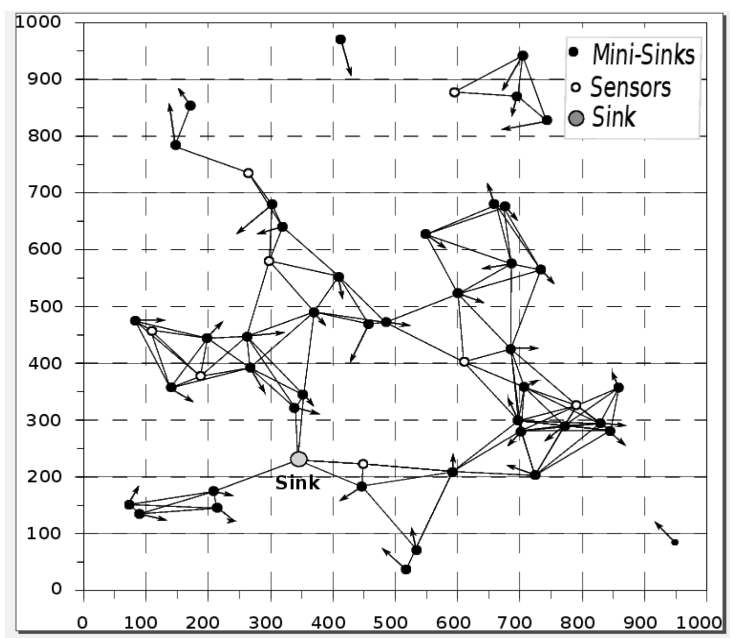

FIGURE 1: Network with mobile mini-sinks.

The geographic network area is a square of side L = 1000m x 1000m.N MSs are randomly placed in this area. Each MS Ni is defined in respect of its coordinates (x, y), and moves from a given position (x_i, y_i)to a new position (xd_i, yd_i) with a velocity [v_{min}, v_{max}], in the range [0...2π].Each MS moves with a different velocity represented in the Figure by differing dashed line styles. When a

MS reaches the locality radius of the sink, it stays there for a time t_i selected in the range [t_{min}...,t_{max}], in order to forward the data that it has collected based on the controlled ECRP towards the sink. After this interval, the MS restarts its displacement process by selecting a new position, and so on.

In the following Section, we outline our Energy Conserving Routing Protocol (ECRP), which has already been presented in [4].

4. ECRP OVERVIEW

The ECRP protocol has been designed to optimize the cost of the forwarding scheme, postpone the onset of congestion and to counteract the high traffic variability in WSNs [19]. The route discovery approach derives directly from the Dijkstra's algorithm. Macgregor et al. [20] present the Meta Dijkstra's algorithm, consisting of iterative applications of Dijkstra's algorithm in a changing topology. Once a path is discovered, its links are deleted from the topology and the performance of the new shortest path in the current graph is evaluated, and so on until a set of maximal paths is found. Unfortunately, such deletion may be too restrictive as it can reject the neighbourhood of the source node from the remaining topology. In other words, it can lead to create a disconnected graph in which the source and destination nodes are not connected together [21, 22, 23].In our new approach, we prefer changing the current topology by adding limited weights to all discovered shortest path edges. We recall that the Meta Dijkstra algorithm corresponds to a particular case of the modified Dijkstra's algorithm where infinite weights are used.

Here briefly is how ECRP works.

Consider a simple topology, as shown in Figure 2. In this topology, we want to extract a set of maximal paths between the transmission nodes S_1 and S_7 randomly chosen. The initial weight of links corresponds to the values seen in the real topology T_0.The modified Dijkstra's algorithm is executed, providing the lowest cost path $P_0 = S_1S_6S_7$ between the transmission sensor nodes S_1 and S_7.Thereafter we increase each link weight in P_0; by adding a constant value C, greater than or equal to the locality radius, the probability of having the same lowest cost path P_0 in the calculation of the new lowest path remains low.

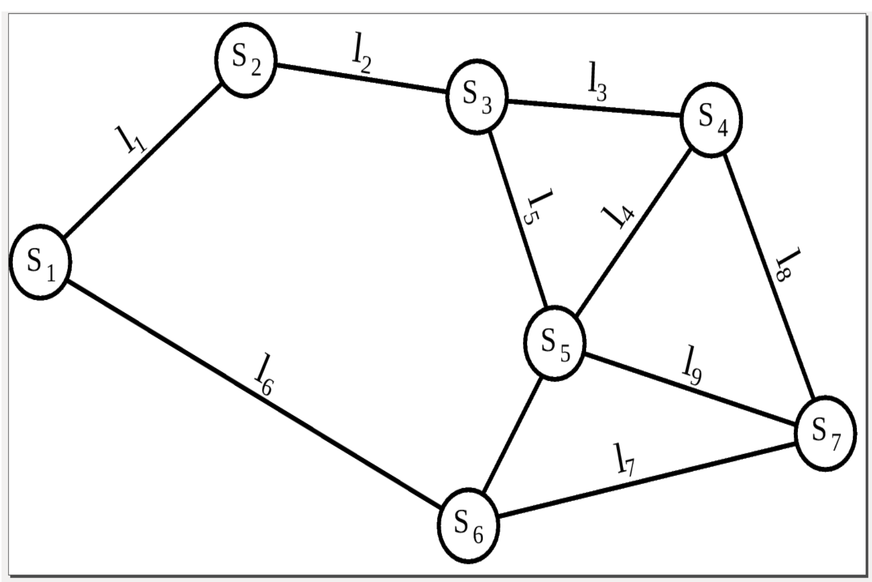

FIGURE 2: Network topology.

Thus, the topology is now described by T_1. We discover the lowest cost path P_1 between the same connection nodes, but now we take the current topology T_1 into account for the calculation. We then increase each link weight in P_1. The topology is now described by T_2. We iterate this process in order to extract a set of maximal routing paths between S_1 and S_7.This iterative process obtains the required maximum number of paths between S_1 and S_7as shown in Table 1.

Paths	Connection links	Hop count
P_1	$S_1S_6S_7$	2
P_2	$S_1S_2S_3S_5S_7$	4
P_3	$S_1S_6S_5S_4S_7$	4
P_4	$S_1S_2S_3S_4S_7$	4

TABLE 1: Paths discovery between sensors S_1 and S_7.

The set of maximal paths extracted is directly applied between sensors and MSs in such a way that, for a transmission between sensors and MSs, the defined traffic is not all carried on a single path, but it is spread over multiple paths. This results in a fair balancing of the energy depletion in order to increase overall network performance. The onset of the global congestion is delayed, as the route diversity modifies the probability of taking a path according to its load. This dynamic path selection implies that the traffic remains more regular for the sensor nodes involved in the routing path. Thus, route diversity appears to be a promising solution for coping with high traffic variability and improving network performance.

We consider in our approach three communication modes while MSs are mobile:

• Multi-MS Mode: each sensor is allowed to connect itself simultaneously to several MSs in order to increase its connectivity capabilities.
The sensor node under consideration stores and updates the lowest cost path towards each accessible MS.
• Multiple routing paths MS mode: each sensor is only interested in the closest MS, although multiple paths are used between a sensor and the closest MSs. These paths are discovered using ECRP.
• MS Point-to-point mode: two MSs want to establish a connection with each other. The lowest cost path is discovered and updated when the network topology changes. In this mode, packets always follow a single path if the topology stays stable. However, the path is updated when the topology change occurs.

4.1 Network Topology

The proposed WSN can be modelled as a connected graph G = (S, E), where S is the set of n stationary sensors, and each E SxS is the set of wireless links that communicate between any two sensor nodes. We use the locality model suggested by Zegura et al. [24] into determine network connectivity. The probability of a link between two sensor nodes S_i and S_j is given by:

$$P = \begin{cases} \alpha \; if \; d \leq R \\ \beta \; if \; d > R \end{cases} \quad (1)$$

$$1 = \alpha + \beta \quad (2)$$

Where d is the Euclidean distance between the sensors $S_i$and S_j. R is a model parameter that defines the locality radius. We visualize R as a value that provides a relationship between physical distance and connection probability. α and β are in [0,1]. In this paper, we select α=1 and β=0.Thus, if $d(S_i, S_j) \leq R$, a bidirectional link is possible between them. This model is relevant to the design of WSNs made up of sensors that have a bounded communication range.

The goal of our approach is to study overall network performance resulting from the mobility of MSs. We also aim to measure the effectiveness of multiple routing path propagation on changing topologies.

4.2 Data Forwarding Procedures

As MSs are mobile, the network topology must be computed in real time in order to see its behaviour. Consider the network topology shown in Figure 1. MSs are represented by black disks with a velocity vector that points to their destination. Sensor nodes are represented by white disks. Arrow length is proportional to the velocity. While each MS is moving, it broadcasts a packet to all sensors in its locality radius in order to inform them that it is a MS. The packet contains the hop count, which is initialized to 1, the identity Id of the MS and the type of sensed data. During the sensing activity of sensors, it may happen that some sensors are connected to many MSs due to their mobility. In order to know which MS is most suitable and presents the lowest cost for transferring the data, each sensor in direct communication with MSs calculates the lowest cost path using ECRP before sending the data to the best MS. During mobility, when each MS arrives at the locality radius of the sink, it stays at the same position for a time t_i, which is as long as is necessary to transfer the data to the sink. During this time, the MS also plays the role of a relay point for its neighboring MSs. The time needed for each MS depends on the amount of data to be transferred to the sink.

5. PERFORMANCE METRICS

The following metrics are used to evaluate our approach:

5.1 Packet Delivery Ratio (PDR)

PDR is the ratio of packets that are received by the sink to the total packets generated by sensors.

$$PDR = \frac{P_{Received} * 100}{\sum_{i=1}^{n} P_{Generated_i}} \qquad (3)$$

PReceived is the total number of data packets received by the sink, PGenerated the total number of data packets generated by sensors and n the number of sensors.

5.2 Throughput

Throughput is the total number of data packets received by the sink in a period of time.

$$Throughput = \frac{\sum_{i=1}^{n} P_{Received_i} * P_{Length}}{SIMU_{Time}} \qquad (4)$$

P*Length* the length of a packet, SIMUTime the simulation time.With higher PDR and throughput being more desirable.

5.3 E_2ED_{elay}

E_2ED_{elay} is the average sum of the difference delay of each data packet is received by the sink and the time a data packet is sent by sensors to MSs.

$$E_2E_{Delay} = \frac{\sum_{i=1}^{P_{Received}} (T_{Received_i} - T_{Ransmission_i})}{P_{Received}} \qquad (5)$$

TReceived is the reception time by the sink, TTransmission the transmission time by each sensor.Smallest is this value indicates the promptness of data delivered to the sink.

5.4 Routing Diversity Overhead (RDO)

We have seen in subsection 4.2 that, while each MS is moving, it broadcasts a beacon message to all sensors in its locality radius in order to inform them that it is a MS. We consider in our experiments that the beacon message exchanged to find the routing paths is a data packet.
We evaluate RDO per sensor due to discover, establish, update and maintain multiple routing paths between sensors and MSs. RDO is the percentage of the total number of packets

exchanged (to calculate, update and maintain multiple paths by each sensor) to the total number of packets that are received by the sink.

$$RDO = \frac{\sum_{i=1}^{n} PExchanged * 100}{PReceived} \quad (6)$$

PExchanged is the total number of packets exchanged by sensors.

5.5 Energy Model

In WSNs, sensors use batteries as their source of energy. In a very large sensor network, sensors are often deployed in a hostile environment where replacing the batteries is not possible. Since sensors are battery-driven, a good choice of energy model is essential to optimize sensor lifetime. It is well-known that data transmission consumes more energy than other activities in WSNs [25]. Our approach considers that sensors are in the active mode and can turn on sleeping mode. In this paper, the energy model used is the same as in [26]. For each pair of sensors (S_i, S_j), the energy consumed when sending a data packet of m bits over one-hop wireless link d can be obtained as:

Sensor sender energy consumption:

$$ETi(m,d) = Eelec * m + Eamp * m * d^2 \quad (7)$$

Sensor receiver energy consumption:

$$ERi(m,d) = Eelec * m \quad (8)$$

The total energy consumed by each pair (S_i, S_j) is:

$$ET(m,d) = ETi(m,d) + ERi(m,d) \quad (9)$$

When a packet is sent along a path P_i ($_i$=1....,q), we must perform an energy decrease operation on each sensor along the path except for the destination sensor. Thus, after a data packet is sent by a sensor, the energy level of that sensor is decremented by the amount of energyrequired to send the data packet. Thus, the RE of a sensor is a fraction of its initial energy value.

RE is the difference between the initial energy and the energy consumed by a sensor:

$$RE = E - ET\,(m,d) \quad (10)$$

EO is the ratio of the total energy exchanged (to discover, establish, update and maintain multiple routing paths)to the total energy consumed to transfer the data by each sensor to MSs.

$$EO = \frac{\sum_{i=1}^{n} E_{Exchanged_i} * 100}{E_T(m,d)} \quad (11)$$

ET_i is the energy consumed for a packet's transmission by the source S_i, ER_j the energy consumed for a packet's reception S_j (1-hop neighbors), Eelec the energy consumed to run the transmitter and receiver circuitry, Eamp the energy of the amplifier, EExchanged to calculate, maintain multiple paths, d the Euclidean distance between (S_i, S_j).

5.6 Network Lifetime (NL)

NL, as the total number of packets that can be transferred in the network before the link between sensors and MSs is disconnected due to the energy depletion. We have seen in that, when a packet is sent along a path P_i ($_i$=1....,q), we must perform an energy decrease operation on each sensor along the path except for the destination sensor. Let T_1 is the real topology of the graph G. After executing ECRP in T_1providing the lowest cost path P_1. After the decreasing operation along the path P_1, we obtain a new topology T_2, in which RE of sensors and link weights are different. If after the decrease operation, RE of a sensor becomes 0, the sensor under consideration and its corresponding links are removed from the new topology. We iterate the procedure of extracting the paths until we obtain the required number of routing paths to transmit the maximum number of data packets to MS. Suppose that P(S_i, MS) is the path between a given sensor S_i and a destination MS, and m bits to be transferred. NL is obtains by maximizing the RE of the path P(S_i, MS).

$$NL = Max \sum_{i=1}^{q} RE\big(P(Si, MS)\big) \qquad (12)$$

6. ANALYSIS AND PERFORMANCE

6.1 Analysis

We implemented our network topology using Qualnet. A topology is totally described by the number of stationary sensor nodes n belonging to the network, their locations, and the link characteristics (l direct edges between sensor nodes).A link is defined by a starting node (head), a finishing node (tail) and a weight (w) needed in the path discovery between sensor nodes. The parameters of analysis are described in Table 2.

Parameters	Description	Value
E	Full Energy of sensor	10000 J
Eelec	Energy to run transceiver/receiver	50 nJ/bit
Eamp	Energy of amplifier	100 pJ/bit
L	Simulation area (m)	1000 x 1000
Packet	Packet length	2 Kbits
Traffic rate	UDP traffic	6 packets/sec
Slength	Session length	[1…60]
B	Bandwidth	250 kbps
R	Locality radius	50m
Movement	Random Way Point	
Routing	Routing protocol	ECRP
V_{max}	Maximum velocity	10mps
SIMUTime	Simulation time	1000s
t_i	Time needed	[0…3]s
n	Number of sensors	[25…100]
N	Number of Mini-Sinks	30

TABLE 2: Simulation parameters.

In all our analysis, we deploy 100 fixed sensor nodes inside a square area L that defines network coordinate bounds. The sink is placed at the corner of the square area L. Each sensor is able to transmit to its lowest cost MS a certain number of packets before its energy is depleted. We analyzed for 30 MSs, since we have showed in our previous work [17] that, using 30 MSs can achieve a fully-connected network. MSs move with a velocity in the range [0…10mps].During the execution of our simulations, a given source and destination pair remains in the evaluated set until communication between them fails due to energy depletion. We repeated 100 times the experiments for the same topology, and then we took the average value of these 100 runs. Initially, each sensor is charged with energy of 10000 Joules. A sensor node was considered non-functional if its energy reached the value 0.

6.2 Performance Results

For the defined network topology, ECRP is applied between a selected sensor and the closest MS. As a consequence, packets can be transmitted over multiple routing paths until the network topology changes to a new configuration. We recall that in the case of a single sink and the mobile sink [5], a single packet is transmitted between each pair (S_i, S_j). In our approach, as multiple routing paths are used between sensors and MSs, we assume that many packets are transmitted between each pair (S_i, S_j).

We used simulations to investigate:

- The PDR and Throughput due to the use of MSs.
- The E_2ED_{elay} due to the mobility of MSs.
- The effect of session length (k) on overall NL and RE.
- The effect of locality radius (R) on overall NL and RE.
- The effect of network density on overall NL and RE.
- The EO and RDO due to calculate and maintain multiple routing paths.

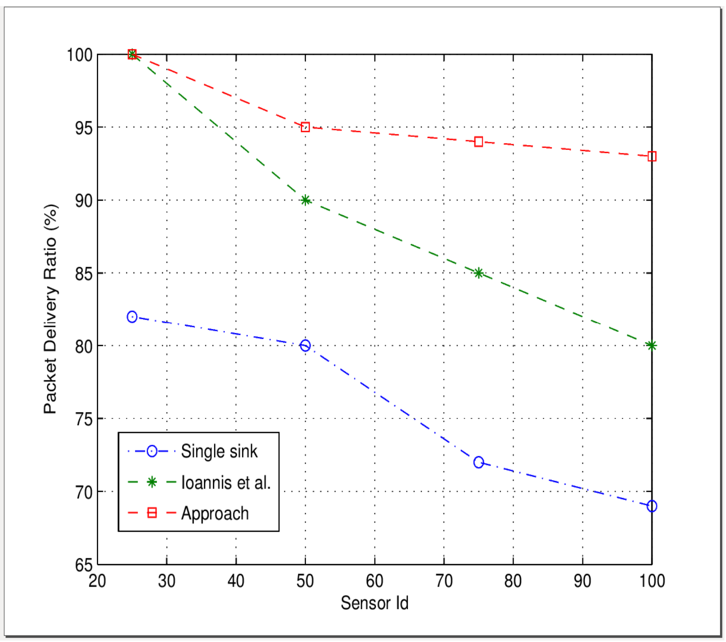

FIGURE 3: PDR vs. Number of sensors.

Figure 3 shows the results of PDR as a function of the sensor Ids. We observe from Figure 3 that, we have the same PDR as Ioannis et al. [5] with 25 sensors. When the number of sensors varies between [25...100], the single static single presents a small percentage of PDR. Hence, Ioannis et al. achieve a higher PDR than the case of a single static sink. In all cases, our Mini-Sink approach achieves the better PDR with an average of 95.5%, compared to 88.55% for Ioannis et al. and 75.75% for the single static sink.

Figure 4 shows the results of throughput as a function of the velocity. We recall that the throughput depends on the velocity of MSs. It can be observed from Figure 4 that, the throughput decreases with increase velocity. We can see that the maximum throughput is achieved with the velocity of 2.5mps. When the velocity varies between [2.5 - 10]mps, our approach outperforms Ioannis et al. and the single sink with an average of 11.24% and 35.94% respectively. We can conclude that, increasing the velocity of MSs degrades the throughput since some sensors may not able to transfer the data to MSs on time.

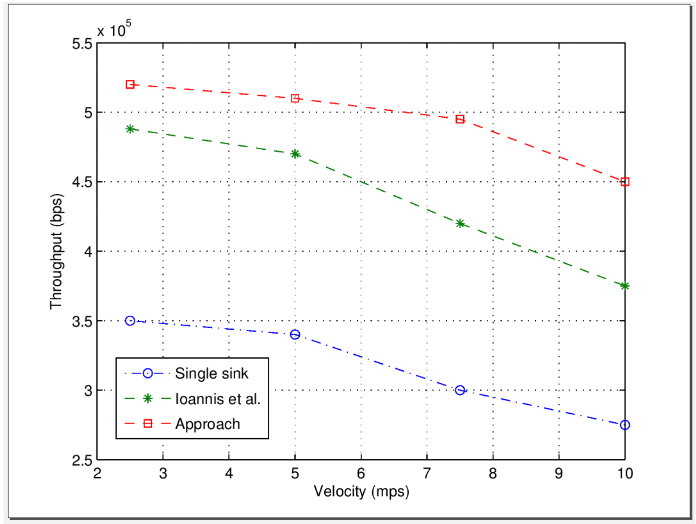

FIGURE 4: Throughput vs. Velocity.

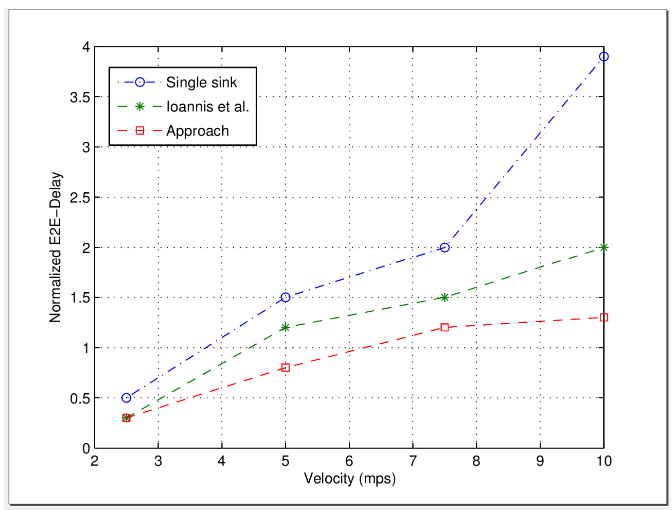

FIGURE 5: E_2ED_{elay} vs. Velocity.

Figure 5 shows the normalized E_2ED_{elay} as a function of the velocity of MSs. We can see that the single static sink presents the large E_2ED_{elay}.That is due to the fact that whenever a sensor wants to send the data, a sensor performs a route discovery process which takes more time. Every sensor extracts and records information before forwarding towards the sink via intermediate sensors instead of MSs as in our approach. Ioannis et al. present the lowest E_2ED_{elay}compared to the single static sink. Figure 5 shows that with the increasing velocity of MSs, our approach achieves the smallest E_2ED_{elay} than Ioannis et al. and the single static sink.

We evaluate now the overall NL. In the single and mobile sink [5], a single packet is transmitted in Session length (Slength) between each pair (S_i, S_j). We assume that k packets are transmitted in each Slength between each pair (S_i, S_j).We then vary the value of k in order to observe the behaviour of our approach and the techniques implemented.

Figure 6 shows the results of NL as a function of Slength. We send k packets at a time for each Slength. We observe from Figure 6 that, when we vary Slength between [1...60], Ioannis et al. achieve better NL than the case of a single static sink. In all cases, our Mini-Sink approach outperforms Ioannis et al. by around 16% and the single static sink by around 40%.

Figure 7 shows the impact of the locality radius on NL. We can see that when the locality radius is less or equal to 35m,the single static sink improves NL than Ioannis et al. and our approach by around 14% and 5% respectively. While, when the locality radius varies between [40...100]m, our approach significantly outperforms Ioannis et al. and the single static sink by around 5% and 20% respectively.

Figure 8 shows the results of the RE vs. Slength. We see that in all the three algorithms, RE increases with increasing Slength. In the case of a single static sink, the forwarding scheme uses multi-hop along the shortest path towards the sink. We observe that Ioannis et al. improve RE than the single static sink by around 20%. Our approach still outperforms Ioannis et al. in terms of RE by around 15% and the single static sink by around 31%.

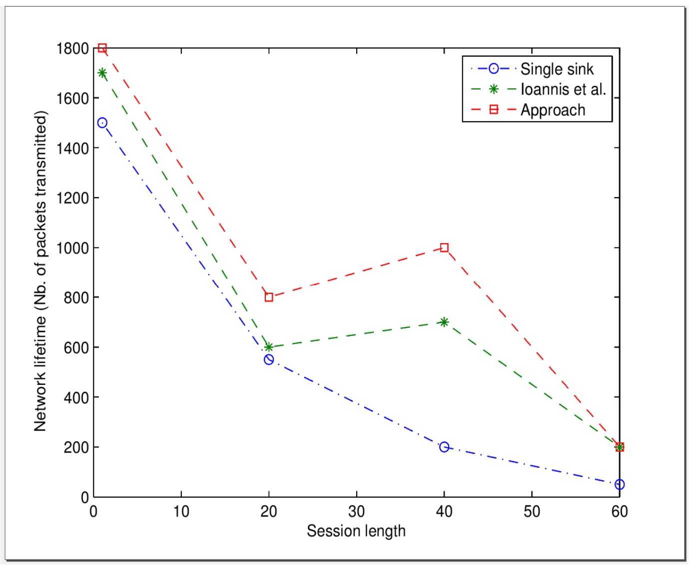

FIGURE 6: Network lifetime vs. Session length.

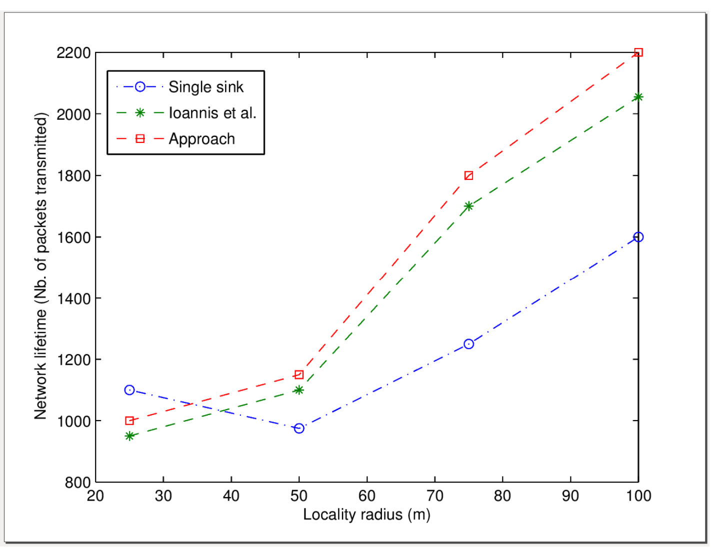

FIGURE 7: Network lifetime vs. Locality radius.

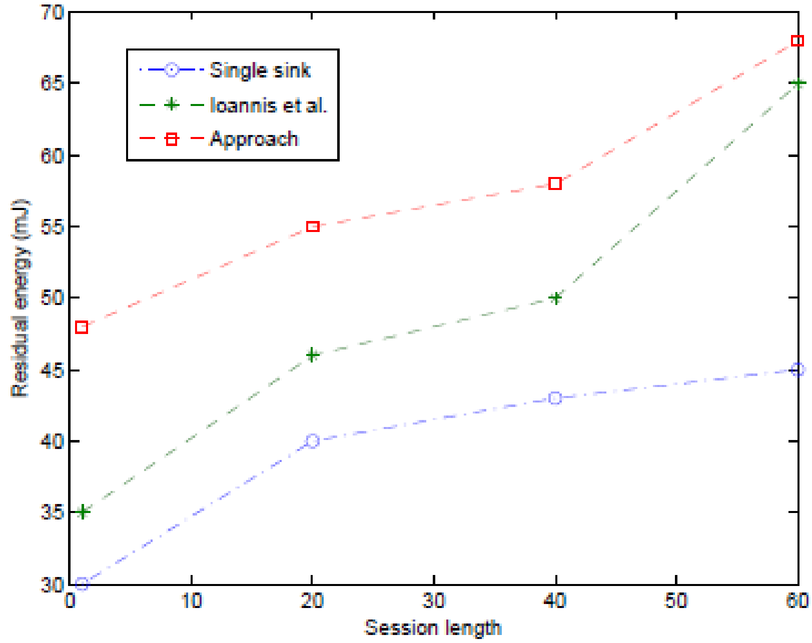

FIGURE 8: Residual energy vs. Session length.

Figure 9 depicts the impact of the locality radius on RE. We see that, as the locality radius varies between [25...100]m, the RE of all the three techniques decreases considerably. That means the locality radius has a strong impact on the RE. In all the cases, our approach outperforms Ioannis et al. and the single static sink by around 36% and 50% respectively.

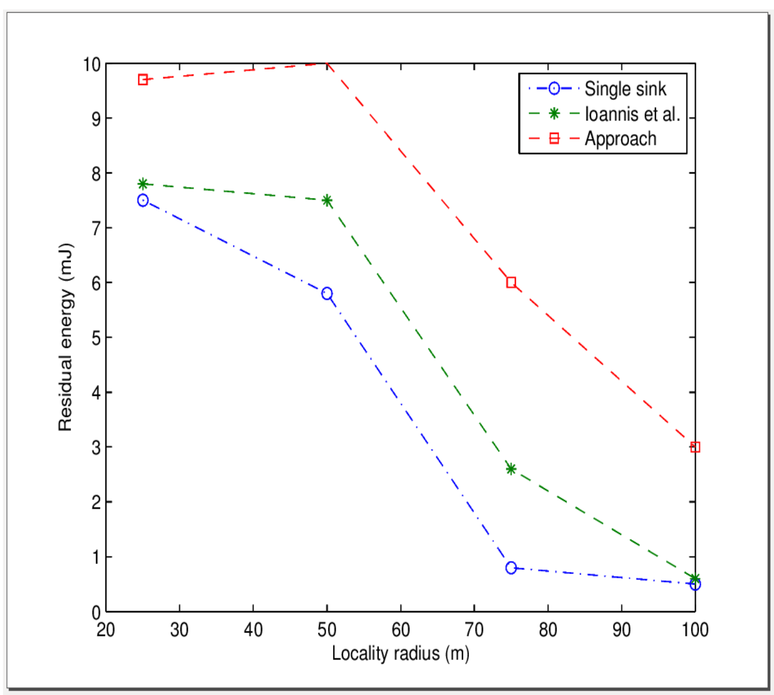

FIGURE 9: Residual energy vs. Locality radius.

In order to understand the behaviour of our approach, we evaluate our algorithm between [100...300] sensors. Figure 10 and Figure 11 depict the average NL and RE as a function of network density. We observe that, when we increase the number of sensors by keeping the locality radius constant, the results obtained by Ioannis et al. are very close to our approach in terms of NL as shown in Figure 10.Ioannis et al. perform better than the case of a single static sink. In terms of the maximal RE as shown in Figure 11, our approach still outperforms Ioannis et al. and the single static sink by around 45% and 63% respectively.

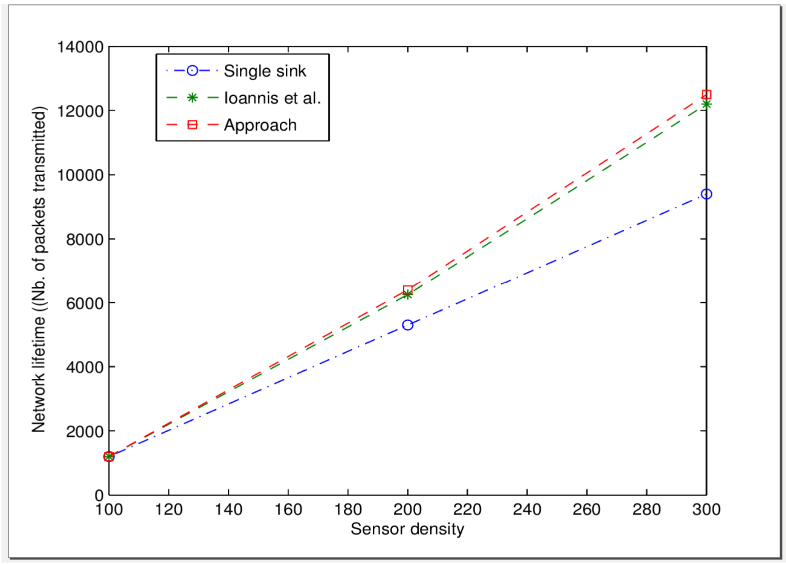

FIGURE 10: Network lifetime vs. Network density.

Figure 12 and Figure 13 show the evolution of EO and RDO as a function of sensor Ids. We can see from Figure 12 that, our approach performs better Ioannis et al. and the single sink in terms of the maximum EO by each sensor with around 11%, 20% and 35% respectively. For the average EO, our approach presents an average EO with around 7.75%, Ioannis et al. around 12.25% and the single sink around 21.75%.Statistically, our approach outperforms Ioannis et al.

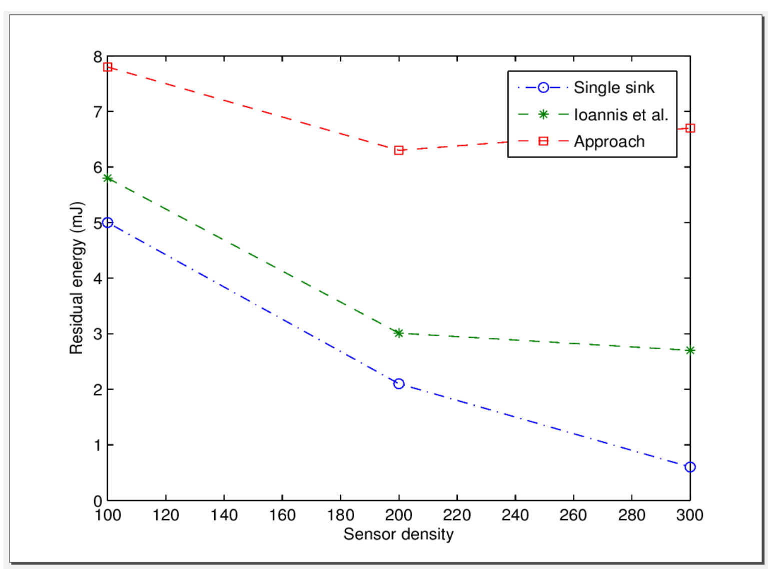

FIGURE 11: Residual energy vs. Network density.

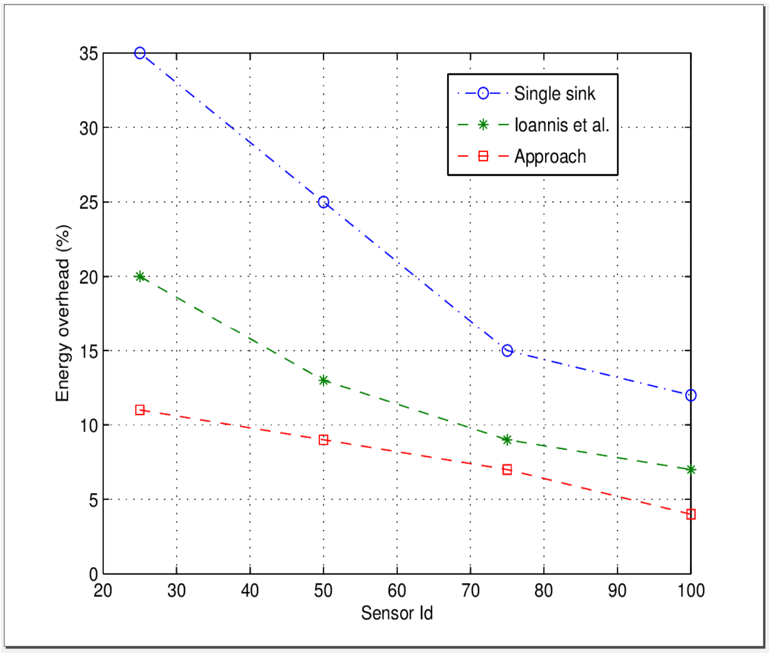

FIGURE 12: Energy overhead vs. Sensor Id.

and the single sink with around 58% and 180% respectively. In Figure 13, we observe that our approach and Ioannis et al. used the lowest beacon packets to find the routing paths compared to the single static sink. That is due to the fact that the single static sink uses the simple flooding in the route discovery process, and needs a higher number of beacon messages if the battery fails.
Our approach improves RDO than Ioannis et al. and the single sink with an average of around 14.75% and 78.51% respectively. This happens because our approach needs less beacon messages to discover and maintain multiple routing paths to MSs.

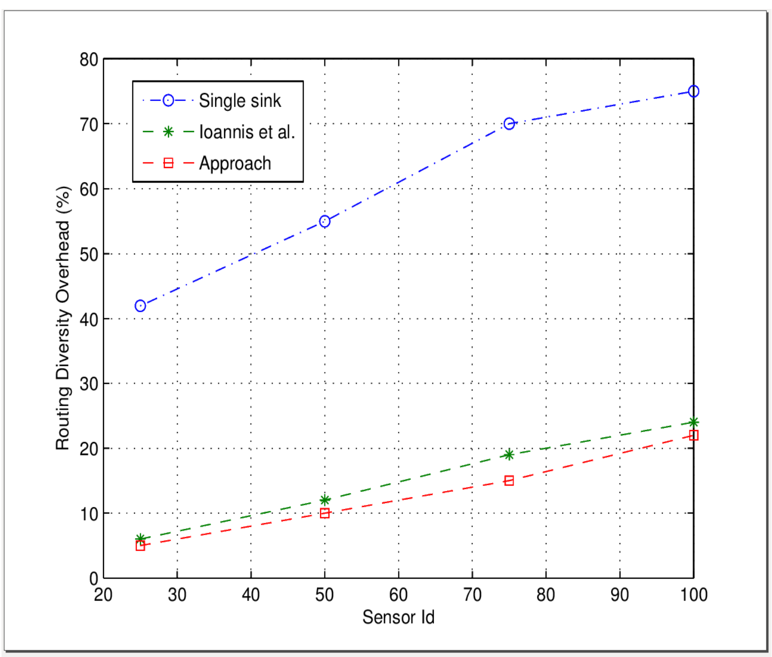

FIGURE 13: RDO vs. Sensor Id.

7. CONCLUSION

In this paper, we propose the use of many MSs, instead of a single sink for collecting data in order to improve WSN performance. One or more MSs are mobile and move according to a controlled arbitrary mobility model inside the sensor field in order to collect data within their coverage areas and forward it towards the sink. ECRP, based on route diversity, is implemented in MSs and sensors in order to optimize the transmission cost of the forwarding scheme. A set of multiple routing paths between MSs and sensors is generated to distribute the global traffic over the entire network. We compare the results obtained with those for a single and mobile sink, and show that our solution can achieve better network performances as PDR, Throughput, E_2ED_{elay}, NL, RE, EO and RDO.

In future works, we will define aggregation mechanisms on sensors and evaluate the impact of interference between sensors and MSs.

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