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A novel energy efficient routing scheme for wireless sensor networks

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ABSTRACT

In the current rapid developing and smart world, the wireless sensor networks domain is among the most emergent fields with plenty of applications such as healthcare, wildlife, environmental monitoring, defense, and landslide detection. Distribution of cluster heads along with the selection of cluster heads is essentially vital for optimizing various network performance parameters. In this paper, a novel energy efficient routing scheme based on probabilistic sector wise clustering has been proposed, which results in energy saving in conjunction with superior network lifetime for wireless sensor networks. In the proposed routing technique, the sensing field is divided into multiple sectors and clusters in five different types. Nodes in the sector can communicate directly with the base station in one-hop or through the gateway node in two-hops. Nodes in the cluster communicate to the base station through the cluster head in three-hops. The simulation results of all five types are compared in terms of their life span. Life span of the network is analyzed by considering the round number in which the first node dies, the round number till which 80% of the nodes are alive, 50% of nodes are alive and 20% of the nodes are alive.

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1. INTRODUCTION

Wireless sensor network (WSN) is the collection of low cost, small size, battery operated sensor nodes, which are capable of sensing, processing, receiving and transmitting data. The sensor nodes generally communicate among themselves over a wide range of area and also with base stations (BS) [1], [2]. The deployed sensor nodes may be assigned with various types of functions and applications such as thermal, health monitoring, bio-medical, agriculture, and security surveillance. The key parameters of a good WSN are lesser energy consumption, higher throughput, better network lifetime, and cost effectiveness [3]. However, a standard or traditional WSN is a widespread package of abundant sensor nodes. The designing of WSN involves significant characteristics along with multiple controls and constraints. These designed networks are consisting of plenty of sensor nodes capable of receiving the data from an extremely unreachable isolated areas and send the collected data to the provisional unit known as 'Sink'. Additionally, as some nodes are deployed in extremely isolated areas and the sensor node batteries are of limited capacity, replacing the discharged batteries or recharging the batteries also becomes one of the major constraints for the WSN [4], [5].

Any sensor node can transmit the sensed data directly to the base station in a single-hop. But the amount of energy spent in transmitting the data depends on the radio communication distance between the sensor node and the base station [6]. A lot of research has been done to devise an algorithm which can reduce the power consumption. Clustering is one of this kind. In clustering, the entire sensing area is divided into multiple clusters. Each cluster is having a cluster head (CH) which collects the data from all the sensor nodes in that cluster and forwards the aggregated data to the base station [7], [8]. Low energy adaptive clustering hierarchy (LEACH) is the most primitive protocol based on hierarchical routing. In hierarchical routing technique, the entire network area is divided into various small clusters and one of the nodes within the cluster is selected as cluster head [9]-[13]. These cluster heads collect the data from all the sensor nodes of the cluster and transmit the aggregated data to the base station. Nodes which are selected as cluster heads consume more energy and hence drain the battery faster. To have the uniform way of battery consumption, the role of cluster heads is made rotating [14]-[17]. Normally, every sensor node will get a fair chance of becoming the cluster head for at least one round. LEACH operates in multiple rounds. Each round consists of two phases, namely, cluster formation phase and data transmission phase. In the cluster formation phase, the elected cluster head broadcasts the advertisement message to the neighboring nodes. The interested node joins the cluster by sending back an acknowledgement to the cluster head. In the data transmission phase, the nodes send data to the cluster head in the allocated time-division multiple access (TDMA) slot [18]-[20].

A wide range of hierarchical based routing protocol techniques have been proposed on the basis of this basic standard LEACH algorithm. In all these techniques, the key objective is to improve the life span of the sensor network by appropriately selecting the cluster head, division of sensing area into multiple sectors and clusters, type and shape of sectors and clusters and multiple–hop data communication [21]-[23].

2. METHOD

This section covers the detailed discussion of the proposed routing scheme. As every node has to sense, process, receive and transmit huge amount of data, there is a need of an algorithm which does all these tasks with minimum power consumption. As already mentioned, replacement of the dead batteries or recharging the depleted batteries is not possible, available battery power has to be used with minimum consumption. It has been proposed here that, by wisely dividing the sensing area into sectors and clusters, lifespan of the sensor node and also the sensor network can be increased. The nodes which are very near to the base station (sector-1) will be directly communicating to the base station instead of transmitting the data through gateway node. Thus, these nodes will be communicating to the base station using single hop. Further, the nodes in the sector 2, will send the packets to the gateway node and from there data will be transmitted to the base station. Thus, these nodes communicate with base station using two hops. Nodes in the cluster1 and cluster2 will be communicating to the base station through cluster head, gateway node using three hop communication.

2.1. Network model

For the proposed routing technique, sensing area of dimensions WxL has been considered and a total of ‘n’ sensor nodes have been deployed. Further, these deployed nodes are assumed to be static throughout the duration of the network simulation. These sensor nodes are responsible for efficient data transmission to the corresponding base station either directly or through the cluster head and gateway node. In addition, the base station may be situated anywhere inside the designed sensor network area or even out of the network premises. Moreover, the network area is further sub categorized into various clusters and sectors with a cluster head (CH) allocated to each cluster. These cluster heads are responsible for collecting the data from all the nodes belonging to the cluster, aggregating the data and sending the aggregated data to the base station. Figure 1 shows the deployment of sensor nodes over the sensing area. Sensing area of (200x200) is considered. 100 nodes are deployed in the sensing area. For the simulation, random type of node deployment is used. The deployed sensor nodes are represented by symbol ‘SN’, where i^{th} sensor node is represented as SN_i and subsequent set of deployed sensor node is represented as:

$$SN = SN_1, SN_2, SN_3, \dots SN_n$$

All the deployed nodes are treated as homogeneous having similar network parameters or characteristics and sensing. As all the deployed sensor nodes initially have same energy levels and competence levels. All nodes are eligible for getting selected as cluster head (CH).

2.2. Radio energy model

First order radio energy model has been used here to analyze the simulation. This model includes energy dissipation parameters for various phases such as data transmission, data reception, data aggregation for all the deployed sensor nodes. Further, the radio energy dissipation model [24]-[26] with data packet transmission capability of 'b' bit message and then the data packet reception covering the distance of 'r' is given by (1)-(3).

$$E_{TRS}(b,r) = \begin{cases} b * E_{cons} + l * \alpha_f * r^2, r < r_0 \\ b * E_{cons} + l * \alpha_m * r^4, r \geq r_0 \end{cases} \quad (1)$$

$$E_{cycle} = b\left(2 * n * E_{cons} + n * E_{Aggr} + n * \alpha_f * {r_{CH}}^2 + C * \alpha_m * {r_{BS}}^4\right) \quad (2)$$

$$E_{RCV} = b * E_{cons} \quad (3)$$

$$r_{CH} = \frac{w}{\sqrt{2*pi*N}} \quad (4)$$

$$r_{BS} = 0.3825 * w \quad (5)$$

$$N_o = \sqrt{\frac{n}{2*pi}} * \sqrt{\frac{\alpha_f}{\alpha_m}} * \frac{w}{{r_{BS}}^2} \quad (6)$$

$$r_o = \sqrt{\frac{\alpha_f}{\alpha_m}} \quad (7)$$

Where, E_{TRS} is the energy consumption during single bit data transmission, E_{RCV} is the energy consumption during single bit data reception, E_{cons} is the total cumulative energy consumption during data transmission and data reception phase, E_{cycle} is the total energy consumption during single bit transmission for a particular cycle throughout the designed sensor network area, E_{Aggr} is the data aggregation energy consumption in selected cluster heads throughout the designed wireless sensor network area, *w* is one of the dimension of the designed wireless sensor network area, r is the distance between transmitter sensor node and receiver sensor node, α_m is the applicable amplification factor for multipath model, α_f is the applicable amplification factor for free space model, *n* is the total number of deployed sensor nodes throughout the designed wireless sensor network area, *N* is the total number of clusters structured throughout the designed wireless sensor network area, N_o is the total optimal number of available clusters the designed wireless sensor network area, r_0 is sensor network cross-over distance, r_{CH} is the average distance between the particular deployed cluster nodes and selected cluster head within the particular cluster, and r_{BS} is the average distance between the cluster head for selected particular cluster and the corresponding base station for the designed wireless sensor network.

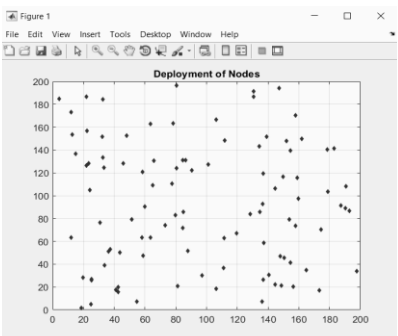

Figure 1. Deployment of sensor node

2.3. Heterogeneous method of sectoring/clustering

In the proposed model, a modified way of sectoring/clustering in used. If the sensor nodes deployed are near to the base station rather than to the gateway node, then these nodes can directly communicate with the base station. In addition, if the nodes are in the vicinity of the gate way node, then instead of creating one more cluster, these nodes can directly communicate to gate way node. In turn the gateway node can forward the aggregated data to the base station. Five different types of creating sectors and clusters are discussed and the network life time is compared for all the five types. Further, the dependence of certain network parameters over the network life time is discussed in detail with the help of simulation results.

For the simulation, it has been assumed that the base station is outside the sensing area. A sensing area of 200x200 meters is considered. Base station is assumed to be at the location (100, 300) and gate way node is assumed to be at the location (100, 100). With these assumptions and considerations, five types of sectoring are done as shown in.

2.3.1. Type 1 categorization

In this type, all the nodes within the range (X–axis->0 to 200, Y–axis->160 to 200) are made to fall in the sector-1. All these nodes being close to the base station rather than the gateway node, communicate directly with the base station in single-hop. The nodes within the range (X–axis->70 to 140, Y–axis->0 to 160) are made to fall in the sector-2. The nodes that lie in this sector–2, will send the data to gateway nodes and in-turn the gateway node transmits it to the base station. Thus, all these nodes communicate with the base station in two-hops. Further, the nodes within the range (X–axis->0 to 70, Y–axis->0 to 160) are made to fall in the cluster-1, and the nodes within the range (X–axis->140 to 200, Y–axis->0 to 160) are made to fall in the cluster-2.

2.3.2. Type 2 categorization

In this type, all the nodes within the range (X–axis-> 0 to 200, Y–axis->160 to 200) are made to fall in the sector-1. The nodes within the range (X–axis->70 to 140, Y–axis->60 to 160) are made to fall in the sector-2. Further, the nodes within the range (X–axis->0 to 70, Y–axis->0 to 160 and X–axis->70 to 100, Y–axis->0 to 60) are made to fall in the cluster-1, and the nodes within the range (X–axis->140 to 200, Y–axis ->0 to 160 and X–axis->100 to 140, Y–axis->0 to 60) are made to fall in the cluster-2.

2.3.3. Type 3 ctegorization

In this type, all the nodes within the range (X – axis -> 0 to 200, Y – axis -> 160 to 200) are made to fall in the sector -1. Nodes within the range (X – axis -> 70 to 140, Y – axis -> 60 to 160) are made to fall in the sector -2. Further, The nodes within the range (X – axis -> 0 to 70, Y – axis -> 0 to 160 and X – axis -> 70 to 100, Y – axis -> 0 to 60 and X – axis -> 60 to 100, Y – axis -> 140 to 160) are made to fall in the cluster -1, and the nodes within the range (X – axis -> 140 to 200, Y – axis -> 0 to 160 and X – axis -> 100 to 140, Y – axis -> 0 to 60 and X – axis -> 100 to 140, Y – axis -> 140 to 160) are made to fall in the cluster -2.

2.3.4. Type 4 categorization

In this type, all the nodes within the range (X – axis -> 0 to 200, Y-axis -> 160 to 200) are made to fall in the sector -1. The nodes within the range (X – axis -> 0 to 200, Y – axis -> 50 to 120) are made to fall in the sector -2. Further, nodes within the range (X – axis -> 0 to 70, Y – axis -> 0 to 160 and X – axis -> 70 to 100, Y – axis -> 0 to 60 and X – axis -> 60 to 100, Y – axis -> 140 to 160) are made to fall in the cluster -1, and the nodes within the range (X – axis -> 140 to 200, Y – axis -> 0 to 160 and X – axis -> 100 to 140, Y – axis -> 0 to 60 and X – axis -> 100 to 140, Y – axis -> 140 to 160) are made to fall in the cluster -2.

2.3.5. Type 5 categorization

In this type, categorization of the sensing area is same as that of Type 4 except that the gateway node is move to center of the entire sensing aread. The location of the gateway node is changed from (100, 80) to (100, 100). This helps to analyse the impact of base station location on the network lifetime.

3. RESULTS AND DISCUSSION

The implementation of the proposed energy efficient routing scheme is done by using MATLAB software. The network related parameters used for the simulation are listed in Table 1. Here, total 100 wireless sensor nodes have been deployed in 200 x 200 m^2area at random. The data packet size is taken as 2000 bits per message. Each type of the node categorization is simulated by varying the parameters such as message size, initial node energy, location of the base station. The corresponding values considered are listed in Table 2. Lifespan of the wireless sensor nodes and the network for all these types are compared by considering the round numbers in which the first node dies (FND), 20 % of the nodes die, 50 % of the nodes die and 80 % of the nodes die.

Table 1. Network parameters used for the simulation

Parameter	Value
Area of Designed Wireless Sensor Network	200m x 200m
Total Number of Deployed Sensor Nodes	100
Average Data Aggregation Energy (E_{Aggr})	5nJ/bit/message
Initial Energy of Deployed Sensor Node (E_o)	0.5 J
Energy Consumption for Data Reception (E_{RCV})	50nJ/bit
Energy Consumption for Data Transmission (E_{TRS})	50nJ/bit
Amplification factor for Multi-path (α_m)	0.0013pJ/bit/m^4
Amplification factor for Free Space (α_f)	10pJ/bit/m^2
Average Probability (P_{avg})	0.1
Message Size	2000 Bits

Table 2. Parameters varied for the analysis

Parameter varied	Values considered		
Message Size	1000 bits	2000 bits	4000 bits
Initial Node Energy	0.5 J	0.75 J	1 J
Base Station Location	(100, 200)	(100, 250)	(100,300)

3.1. Change in the message size

Simulation results obtained by changing the message size for all 5 types are tabulated in Table 3. Lifespan of the network is compared by considering the round number in which the first node of the network dies (FND), the round number till which 80 % of the nodes are alive, the round number till which 50 % of the nodes are alive, the round number till which 20 % of the nodes are alive. These values are obtained by for the message size of 1000 bits, 2000 bits, 4000 bits for all the proposed five types. Table 4 shows the overall comparison of all five types for different message sizes. It has been assumed that, the network becomes non-functional when 80% of nodes die. Therefore, the lifespan is considered as the round number till which 80% of the nodes are alive.

Figure 2 shows the comparison of node survivals by changing the message size. Figures 2(a) to 2(e) show node survivals of all types and Figure 2(f) shows comparison of all types. It is evident from the graphs that, as the message size increases, the energy consumed for transmitting the data packets also increases. Hence the lifespan of the network for 1,000-bit message is maximum and the lifespan of the network for 4,000-bit message is minimum. Further, Type 1 is having the maximum lifespan in terms of number of rounds for the message sizes of 1,000 bits, 2,000 bits and 4,000 bits in comparison with other four types.

3.2. Change in the initial node energy

Simulation results obtained by changing the initial node energy for all 5 types are tabulated in Table 5. Lifespan of the network is compared by considering the round number in which the first node of the network dies (FND), the round number till which 80 % of the nodes are alive, the round number till which 50 % of the nodes are alive, the round number till which 20 % of the nodes are alive. These values are obtained by changing the initial node energy as 0.5 J, 0.75 J and 1 J for all the proposed five types. Table 6 shows the overall comparison of all five types for different values of Initial Node Energy. It has been assumed that, the network becomes non-functional when 80% of nodes die. Therefore, the lifespan is considered as the round number till which 80% of the nodes are alive.

Figure 3 shows the comparison of node survivals by changing the initial node energy. Figures 3(a) to 3(e) show node survivals of all types and Figure 3(f) shows comparison of all types. It is seen from the graphs that, as the initial node energy increases, the nodes will stay alive for a greater number of rounds. Hence the lifespan of the network for the initial node energy of 0.5 joules is minimum and for the initial node energy of 1 joule is maximum. Further, Type 1 is having the maximum lifespan in terms of number of rounds for the initial node energy of 0.5 J, 0.75 J and 1 J in comparison with other four types.

Table 3. Results obtained by changing the message size for all types

Life Span	Type - 1			Type - 2			Type - 3			Type - 4			Type - 5		
	Message Size in bits			Message Size in bits			Message Size in bits			Message Size in bits			Message Size in bits		
	1000	2000	4000	1000	2000	4000	1000	2000	4000	1000	2000	4000	1000	2000	4000
FND	552	268	142	527	273	150	542	288	136	544	276	137	537	301	156
80% Alive	2451	1130	653	2134	1245	726	2125	1256	622	2484	1208	611	2166	1086	561
50% Alive	4051	2029	1029	3791	2054	1014	3984	2058	1000	4168	2067	1021	3965	2010	991
20% Alive	6336	3043	1571	5559	2792	1457	5242	2565	1317	5517	2791	1356	5436	2769	1407

Table 4. Overall comparison of all types for different message sizes

Comparison of all five types for different message size			
Type	Life span of network for		
	1000 bits	2000 bits	4000 bits
Type - 1	6336	3043	1571
Type - 2	5559	2792	1457
Type - 3	5242	2565	1317
Type - 4	5517	2791	1356
Type - 5	5436	2769	1407

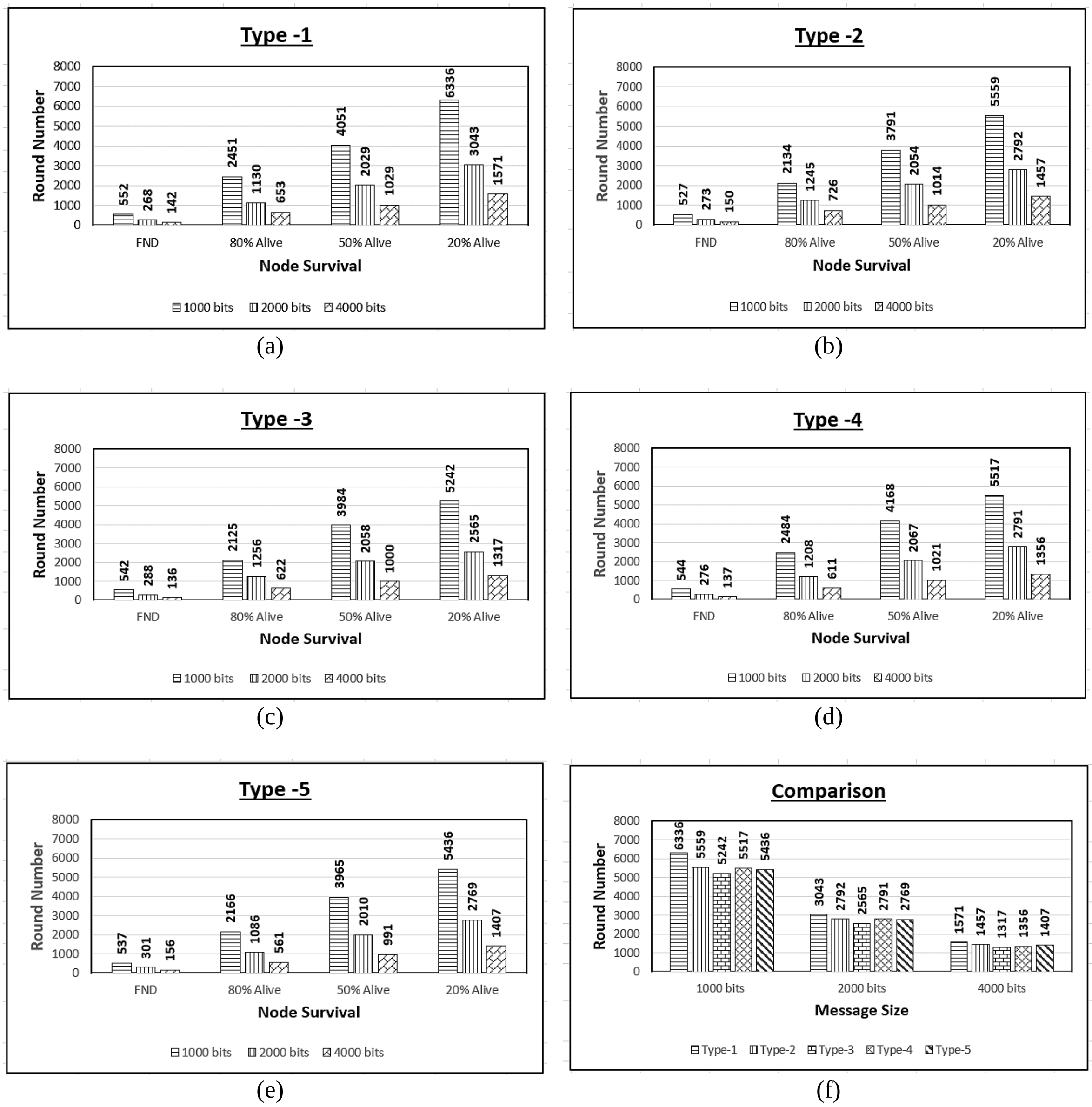

Figure 2. Comparison of node survivals of all types changing the message size; (a) type 1, (b) type 2, (c) type 3, (d) type 4, (e) type 5, and (f) comparison

3.3. Change in the base station location

Simulation results obtained by changing the location of base station location for all 5 types are tabulated in Table 7. Lifespan of the network is compared by considering the round number in which the first node of the network dies (FND), the round number till which 80 % of the nodes are alive, the round number till which 50 % of the nodes are alive, the round number till which 20 % of the nodes are alive. These values are obtained by changing the base station location as (100, 300), (100, 250) and (100, 200) for all the proposed five types. Table 8 shows the overall comparison of all five types for different base station locations. It has been assumed that, the network becomes non-functional when 80% of nodes die. Therefore, the lifespan is considered as the round number till which 80% of the nodes are alive.

Figure 4 shows the comparison of node survivals by changing the base station location. Figures 4(a) to 4(e) show node survivals of all types and Figure 4(f) shows comparison of all types. It is clear from the graphs that, as the base station moves toward the sensing area, the radio communication distance reduces and the energy consumed in transmitting the packets also reduces. Hence the lifespan of the network for the base station location (100, 300) is minimum and for the base station location (100, 200) is maximum. Further, Type 1 is having the maximum lifespan in terms of number of rounds for the base station location (100, 300), (100, 250) and (100, 200) in comparison with other four types.

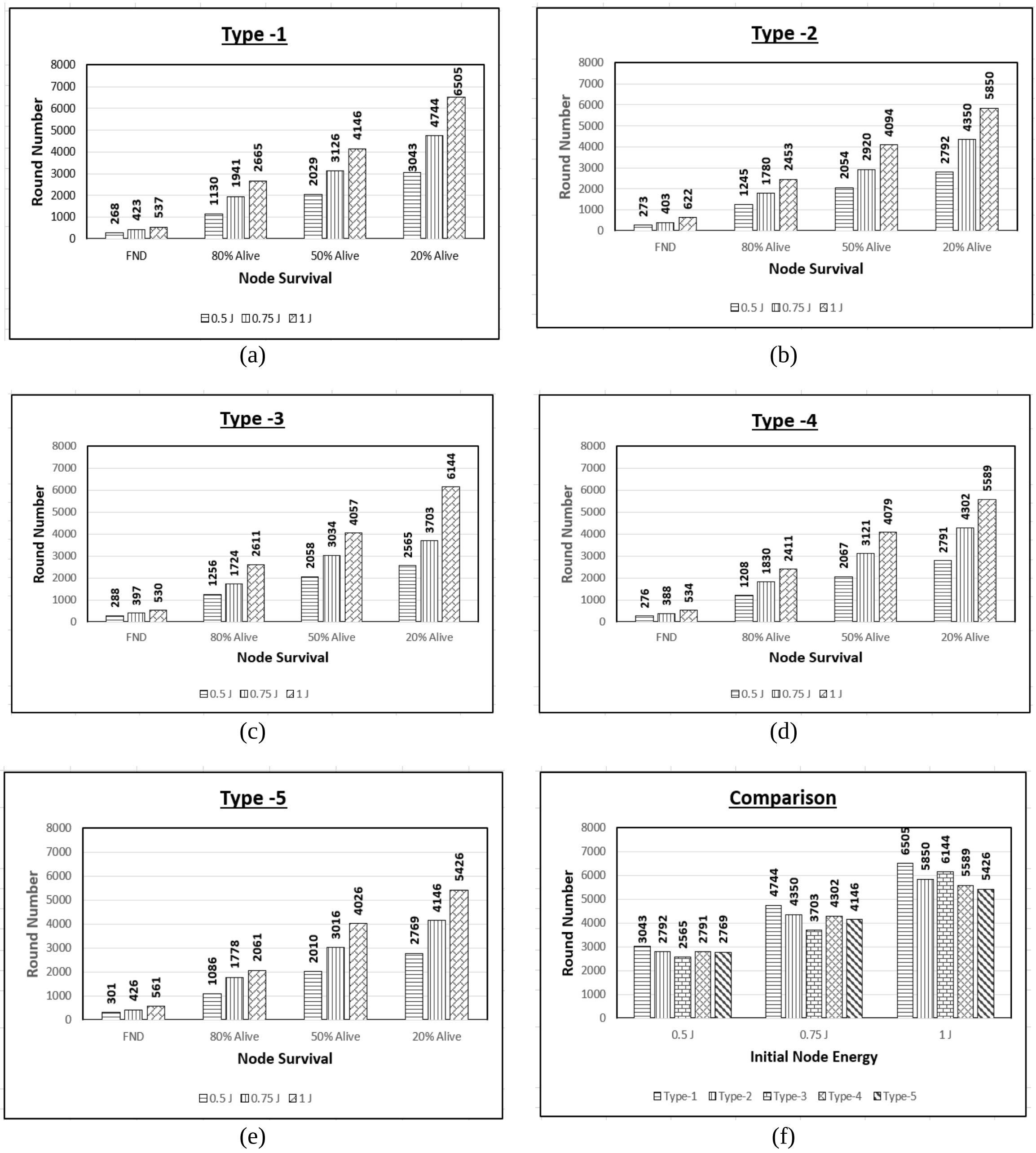

Figure 3. Comparison of node survivals of all types by changing the initial node energy, (a) type 1, (b) type 2, (c) type 3, (d) type 4, (e) type 5, and (f) comparison

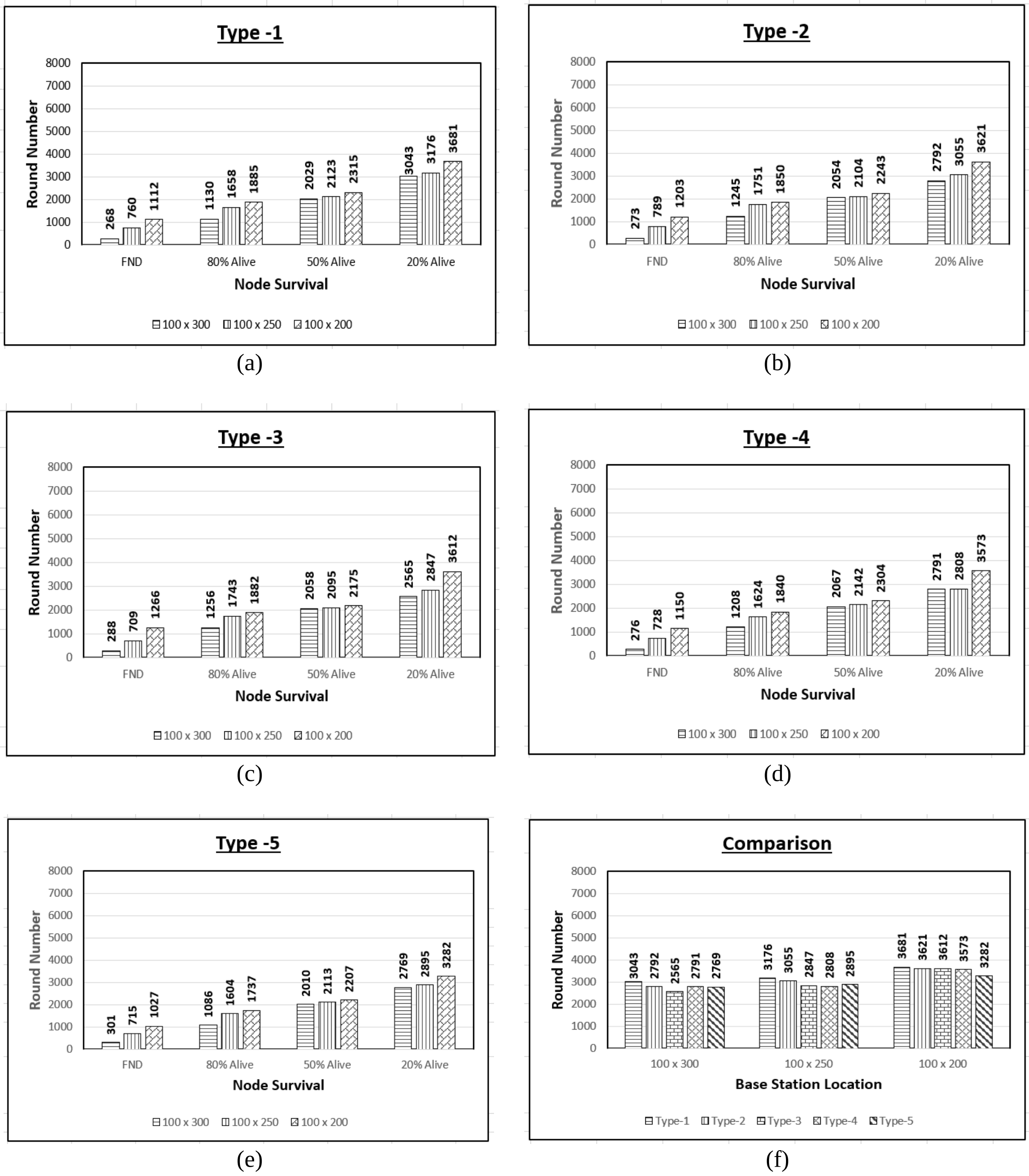

Figure 4. Comparison of node survivals of all types by changing the base station location, (a) type 1, (b) type 2, (c) type 3, (d) type 4, (e) type 5, and (f) comparison

Table 5. Results obtained by changing the initial node energy for all types

Life Span	Type - 1			Type - 2			Type - 3			Type - 4			Type - 5		
	Node Energy (Joules)			Node Energy (Joules)			Node Energy (Joules)			Node Energy (Joules)			Node Energy (Joules)		
	0.5	0.75	1	0.5	0.75	1	0.5	0.75	1	0.5	0.75	1	0.5	0.75	1
FND	268	423	537	273	403	622	288	397	1266	276	388	534	301	426	561
80% Alive	1130	1941	2665	1245	1780	2453	1256	1724	2611	1208	1830	2411	1086	1778	2061
50% Alive	2029	3126	4146	2054	2920	4094	2058	3034	4057	2067	3121	4079	2010	3016	4026
20% Alive	3043	4744	6505	2792	4350	5850	2565	3703	6144	2791	4302	5589	2769	4146	5426

Table 6. Overall comparison of all types for different node energy values

Comparison of all five types for different node energy			
Type	Life span of network for		
	0.5 J	0.75 J	1 J
Type - 1	3043	4744	6505
Type - 2	2792	4350	5850
Type - 3	2565	3703	6144
Type - 4	2791	4302	5589
Type - 5	2769	4146	5426

Table 7. Results obtained by changing the base station location for all types

	Life Span		FND	80% Alive	50% Alive	20% Alive
Type - 1	Base Station Location	(100,300)	268	1130	2029	3043
		(100, 250)	760	1658	2123	3176
		(100,200)	1112	1885	2315	3681
Type - 2	Base Station Location	(100,300)	273	1245	2054	2792
		(100, 250)	789	1751	2104	3055
		(100,200)	1203	1850	2243	3621
Type - 3	Base Station Location	(100,300)	288	1256	2058	2565
		(100, 250)	709	1743	2095	2847
		(100,200)	1266	1882	2175	3612
Type - 4	Base Station Location	(100,300)	276	1208	2067	2791
		(100, 250)	728	1624	2142	2808
		(100,200)	1150	1840	2304	3573
Type - 5	Base Station Location	(100,300)	301	1086	2010	2769
		(100, 250)	715	1604	2113	2895
		(100,200)	1027	1737	2207	3282

Table 8. Overall Comparison of all types for different base station locations

Comparison of all five types for different base station location			
Type	Life span of network for		
	(100, 300)	(100, 250)	(100, 200)
Type - 1	3043	3176	3681
Type - 2	2792	3055	3621
Type - 3	2565	2847	3612
Type - 4	2791	2808	3573
Type - 5	2769	2895	3282

4. CONCLUSION

For analysis of network lifetime, five different types of comparisns were considered. In each of these types, three networks parameters were veried to obtain the results. With the help of the simulation results obtained and the plotted graphs, it can be concluded here that, based on the requirements in term of message size, initial node energy and location of the base station, appropriate type of sectoring/clustering is adopted to increase the life span of the sensor network.

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