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Improved Multiple Gateway Node Based Routing Architecture for Heterogeneous Wireless Sensor Network

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Abstract*: *In modern era, with technologies shifting from wired to wireless technologies, Wireless Sensor Networks (WSNs) play an essential role in advancement of technology. WSNs have limited battery .In this paper, we propose Improved Multiple Gateway Node (MGN) based Routing Architecture (IMRA) that increases both network lifetime and stability period of the network and also improves energy efficiency. It uses the technique of load balancing and considers average energy of the network to improve aforementioned parameters. IMRA is event-driven protocol and has four MGNs with unlimited power which makes this protocol efficient for use in disaster prone areas like earthquakes, forest fires etc. saving millions of lives. Wireless Sensor Networks (WSNs) play an essential role in advancement of technology. Various disasters like earthquakes, forest fires, etc. can be sensed in advance using latest technology in WSNs and preventive measures can be taken. IMRA surpasses other protocols by increasing Stability Period, Half Node Dead and Network lifetime by 58.18%, 55.94% and 52.96% respectively as compared to traditional MRA and by 156.99%, 86.2% and 90.12% respectively as compared to Threshold sensitive Energy Efficient Delay aware Routing Protocol(TEDRP).

Keywords* : *IMRA, Network Lifetime, Stability Period, WSN.

I. INTRODUCTION

WSNs[1,2] are emerging in the modern pace due to their wide range of applications from smart buildings to industrial applications to environment and wildlife monitoring and many more. These are placed[3] haphazardly and sensors used sense some change like change in temperature, pressure, amount of heat, sensitivity change and so on and use that change in value to actuate some action or to provide an alarm as in case of forest fires, volcanic eruptions and so on in order to perform some preventive measures. Wireless sensor networks are of various types naming some of them, are terrestrial WSNs, mobile WSNs, underground WSNs and so on depending on type of applications these are being used for. Wireless Sensor Networks may be reactive(event driven) or proactive. Reactive WSNs are used in applications that require data transmission during some special events like creating alarm in an emergency like in flood prone areas, when possibility of a flood arises, data is sent during that event to prevent destruction of life and habitat.

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Proactive WSNs transmit and receive data throughout it's existence like health monitoring applications. Proactive WSNs consume more energy than reactive WSNs as more transmission is required. WSN can be exploited to the numerous applications [4-6] that are discussed further. These applications need wireless ad hoc networking methods however, it is crucial to point out the difference in the ad-hoc networking and sensor networks which are states as follow.

a) The WSN may have nodes of several orders of magnitude in comparison to ad hoc network.
b) Nodes of WSN are deployed densely and can be damaged with time.
c) The nodes may be homogeneous or heterogeneous [7].While for energy conservation[8], heterogeneous network is preferred.
d) Topological changes are observed more frequently in case of WSN as compared to the ad-hoc networking.

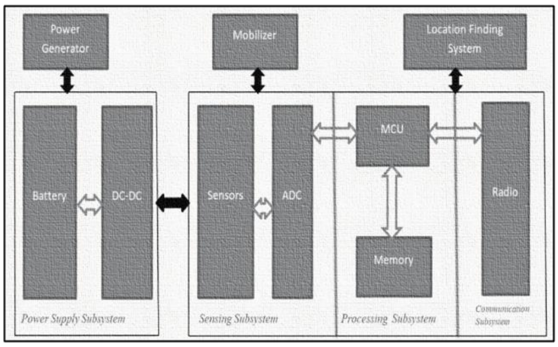

Fig. 1. WSN Framework

For proper energy utilization of WSN, various routing protocols[9,10] are formulated. The routing technique can be Location-based Routing(LR) , Hierarchical Routing , or Flat Routing(FR) . FR approach provides information to user as per the need. No hierarchy is maintained. Data can be routed through any route. While in hierarchical routing technique, a hierarchy is maintained and doesn't allow unneeded data to reach destination. The best route is found and data is transferred via that best and nearest route thus allowing higher remaining energy than the FR for the same number of rounds covered. Hierarchical routing also provides better security of transmitted data than flat routing. In LR, the location of user whom data is to be transferred is a crucial parameter because the route selected depends on it. The location is estimated using GPS so it is a complex and costly routing technique but is very efficient, in fact mandatory, for application where the user or the sink or both are mobile.

In this paper, we are proposing IMRA that provides energy efficient routing .The proposed protocol performs better than MRA and TEDRP considering network lifetime, half node dead , stability period, and the remaining energy. The results are improved using load balancing approach and by considering network's average energy in network operation. The problem of creation of bottleneck in overall operation of network due to fast depletion of higher energy nodes being selected as CHs over and over again is solved by the load balancing approach. The further section discusses related work, radio energy model, working of proposed protocol, results and discussions and conclusion.

II. RELATED WORK

Hu.et.al [11] recommended a novel algorithm for CH selection depending on LEACH. For removing the disadvantages of leach, leach-imp is proposed. This algorithm improves non uniform consumption in nodes. In this algorithm CH is appointed at the centre of each section then neighboring nodes near CH make cluster. By this way communication radius is decreased and transmit power is also decreased. In this proposed algorithm simulation result indicates that throughput and residual energy is improved compared to Leach.

Naranjo et al. in [12] discussed Prolong Stable Election Protocol (P-SEP) that controls instinctive haphazardness of CH selection in each round as compared to SEP protocol. Mittal et al. in [13] proposed Stable Energy Efficient Clustering Protocol (SEECP) that performs numerical calculations to select unique radius around Base Station(BS) for dual hop data communication which reduce energy consumed by far located CHs.

Verma et al. in [14] proposed first protocol to address the harsh environment monitoring by selecting CH depending on distance, residual energy and node density. They used four data sinks outside network to overcome hotspot problem. Tian et.al [15] recommended a novel routing protocol for WSN named "Energy-efficient Chain-cluster Routing protocol (ECR)". This protocol utilizes distributed algorithm with central control and forms two hierarchical chain pattern.

Jang.et.al in [16] proposed Efficient-Clustering scheme with Concentric-Hierarchy (EECCH) algorithm removing the shortcomings of Leach and Leach-C. It is multihop routing based centralized clustering scheme. In this algorithm circles are drawn with BS being the center, BS separates network nodes into fixed levels then different number of cluster member are taken to eliminate the inequality in energy efficiency. Here we achieve proper distribution of CH minimizing energy dissipation of whole network.

III. FLOW OF PROCESSES INVOLVED IN PROPOSED ARCHITECTURE

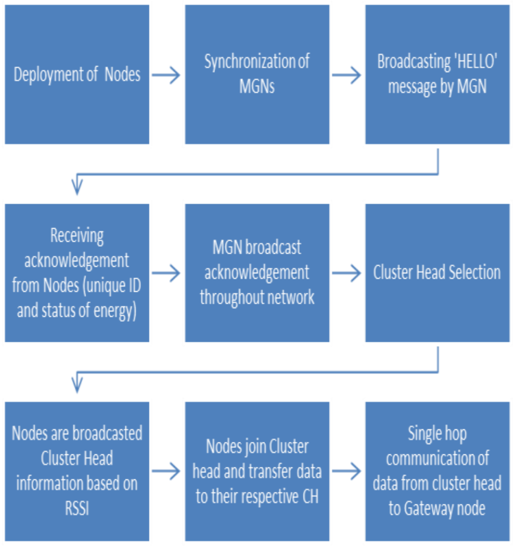

Fig. 2. Process involved in the proposed architecture

IV. RADIO ENERGY MODEL

Energy of transmission of m bits to cover distance w is

$$E_T(m,w) = (m * E_T) + (m * E_F * w^2)$$

if $w \leq w_o$

$$E_T(m,w) = (m * E_T) + (m * E_{mp} * w^4)$$

if $w > w_o$ (1)

$E_T(m,w)$ is the transmission energy of m bits at any distance w. E_F is the free space transmission energy and w_o is threshold distance which measures amount of energy consumed in transmitting data . E_{mp} is multi path transmission of bits.

$$w_o = (E_F / E_{mp})^{1/2} \quad (2)$$

Energy consumption in receiving m bits is:

$$E_r(m) = m * E_{r1} \quad (3)$$

E_{r1} is energy consumption in reception of one bit. $E_r(m)$ is energy consumption in reception of m bits data.

Energy consumed in aggregation of m bits of data is:

$$E_{ag}(m) = m * E_{a1} \quad (4)$$

$E_{ag}(m)$ is energy consumption in aggregation of m bits of data. E_{a1} is energy consumption in aggregating single bit data.

V. WORKING OF PROPOSED PROTOCOL

The working process involves two phases :

- Setting Up Phase
- Data Transfer Phase.

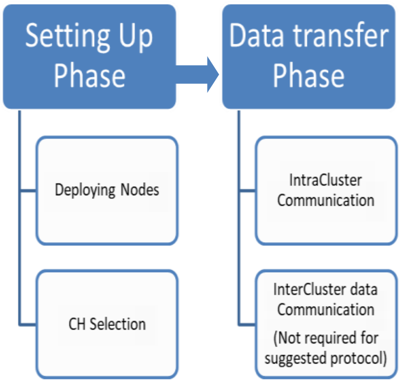

Fig. 3. Working of proposed protocol

A. Deploying Nodes

Define Field of 100m by 100m is considered for deployment of nodes. Nodes are deployed uniformly but randomly. The proposed network is a heterogeneous Wireless Sensor Network with three levels of heterogeneity which give rise to three nodes namely, Normal energy nodes, Advance energy nodes, Super energy nodes. Energy of normal energy nodes is minimum while energy for advance energy nodes is ϵ constant higher than that of normal energy node; energy of super energy nodes is δ times higher than normal energy nodes.

Assuming s to be total nodes, k be fraction of super energy nodes and h be fraction of advance energy nodes, total normal energy nodes, advance energy nodes and super energy nodes are represented by following equations:

$$N_{Super} = s * k$$
$$N_{Advanced} = s * h$$
$$N_{Normal} = s * (1 - k - h) \quad (5)$$

N_{Normal} are total normal energy nodes, $N_{Advanced}$ are total advance energy nodes and N_{Super} are total super energy nodes respectively.

Energy values of each one of nodes discussed above are represented by:

$$E_{Super} = E_n * (1 + \delta) * s * k$$
$$E_{Advanced} = E_n * (1 + \epsilon) * s * h$$
$$E_{Normal} = E_n * s * (1 - k - h) \quad (6)$$

E_{Super} is initiative energy of super energy nodes, $E_{Advanced}$ is initiative energy of advance energy nodes and E_{Normal} is initiative energy for normal energy nodes. E_n is initiative energy for a single normal energy node.

Total energy of network (E_T) is:

$$E_T = E_{Super} + E_{Advanced} + E_{Normal} \quad (7)$$

Average energy of network is:

$$E_{Avg} = (E_{Super} + E_{Advanced} + E_{Normal})/s \quad (8)$$

B. Cluster Head Selection

Firstly, the chances of each node to be CH (P_i) is computed by following set of equations based on threshold energy E_{TH}:

For Normal Nodes,

$$P_i = (P_o * E_r * N_D)/((1 + k * \delta + h * \epsilon) * C_{HG} * E_{Avg})$$
If $E_r \geq E_{TH}$
$$P_i = (0.02 * P_o * E_r * N_D)/((1 + k * \delta + h * \epsilon) * C_{HG} * E_{Avg})$$
If $E_r < E_{TH}$ (9)

P_o is optimal probability for number of CHs, E_{Avg} is average energy for network, E_r is residual energy for each node, E_{TH} is threshold energy given by:

$$E_{TH} = 0.7 * \text{Initial energy} \quad (10)$$

C_{HG} is the distance of each i^{th} node with (x_i, y_i) co-ordinates from its nearest gateway node with (x_{Gi}, y_{Gi}) co-ordinates.

$$C_{HG} = \sqrt{((x_i - x_{Gi})^2 - (y_i - y_{Gi})^2)} \quad (11)$$

N_D is the node density given by the equation:

$$N_D = 1 - \left(\frac{C_{ij}}{100}\right) \quad (12)$$

C_{ij} is the distance between the neighbouring i^{th} and j^{th} cluster members with co-ordinates (x_i, y_i) and (x_j, y_j).

$$C_{ij} = \sqrt{((x_i - x_j)^2 - (y_i - y_j)^2)} \quad (13)$$

For Advance Nodes,

$$P_i = (P_o * E_r * (1 + \epsilon) * L_{Balnc} * N_D)/((1 + k * \delta + h * \epsilon) * C_{HG} * E_{Avg})$$
If $E_r \geq E_{TH}$
$$P_i = (0.02 * P_o * (1 + \epsilon) * L_{Balnc} * E_r * N_D)/((1 + k * \delta + h * \epsilon) * C_{HG} * E_{Avg})$$
If $E_r < E_{TH}$ (14)

L_{Balnc} is the load balancing parameter. Load balancing helps in network longevity as it helps in avoiding the penalization of high energy nodes being selected as CH over and over again irrespective of their energy. It selects a node in its epoch of ten rounds in which it is selected once as a CH. The node which has not become CH yet increases its probability as the epoch tends to get over. The value is kept 0.1 initially for every node considered in the competition for becoming CH. With every increase in the round, the value is enhanced by 0.1 till it reaches 1. As soon as it reaches 1 it becomes CH.

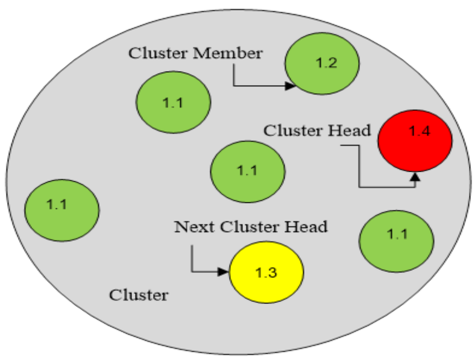

Fig. 4. Load Balancing

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For Super Nodes,

$P_i = (P_o * E_r * (1+\delta) * L_{Balnc} * N_D)/((1+k*\delta+h*\epsilon) * C_{HG} * E_{Avg})$

If $E_r \geq E_{TH}$

$P_i = (0.02 * P_o * (1+\delta) * L_{Balnc} * E_r * N_D)/((1+k*\delta+h*\epsilon) * C_{HG} * E_{Avg})$

If $E_r < E_{TH}$ (15)

After calculation of probability of each node to be CH, T_i threshold value is computed that determine whether the node under consideration will become CH or remain Cluster Member(CM). A random value between (0,1) is generated for each node and compared with the above mentioned threshold value. Finding the random value being less than T_i, the node is selected CH or remains CM.

$$T_i = \frac{P_i}{(1-P_i)*mod\left(r,\left(\frac{1}{P_i}\right)\right)}$$

if node is yet to be cluster head

$T_i = 0$

Otherwise (16)

C. Data Transfer Phase

The proposed protocol is cluster-based WSN comprising of CH, some CMs in each cluster. CM communicate data to CH depending on TDMA termed as intra-cluster communication. Proposed protocol is event-driven and data is transferred from CMs to CH only if sensed value is larger than hard threshold value. All the CHs transfer data to nearest gateway node(total of 4 gateway nodes) through single hop communication so inter-cluster communication is not required. This reduces the amount of energy consumption which might have been dissipated in inter-cluster communication.

VI. RESULT AND DISCUSSION

Various parameters involved in the proposed protocol are shown with their values in Table1. The network scenario can be demonstrated using Figure4. Total energy of the network is 67.5J. This energy drains during transmission , reception and aggregation of data as shown in Figure5. The proposed improved MRA network covers maximum number of rounds before the energy drains completely as compared to MRA and TEDRP protocol which is clearly demonstrated in Table2. Figure6 represent dead nodes vs rounds covered and Figure7 represent alive nodes vs rounds covered.

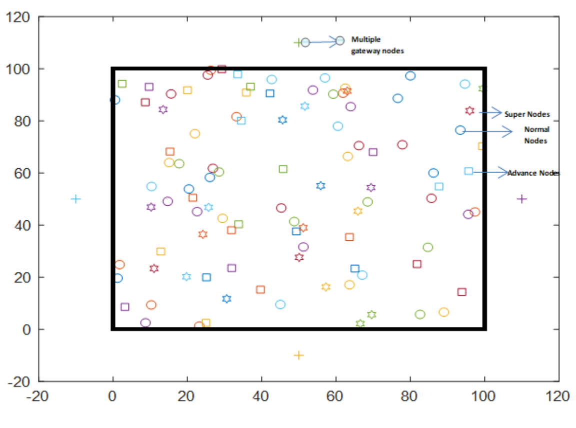

Fig. 5. Network Scenario of IMRA

Table-I: Simulation parameters involved in the proposed work

SIMULATION PARAMETERS	VALUES
Network field	(100*100) m^2
Total nodes	100
Position of 4 gateway nodes	(50,110),(-10,50),(50,-10),(110,50)
Initial energy	0.5 J
Energy consumption to transmit one bit	50 nJ
Energy consumption to receive one bit	50 nJ
Energy consumption to aggregate one bit	5 nJ
E_F (pJ/bit/ m^2)	10
E_{MP} (pJ/bit/m^4)	0.0013
Fraction of super nodes(k)	0.2
Fraction of advance nodes(h)	0.3
δ	1
ϵ	0.5
W_o	87m
Optimal probability of number of Cluster heads	0.1

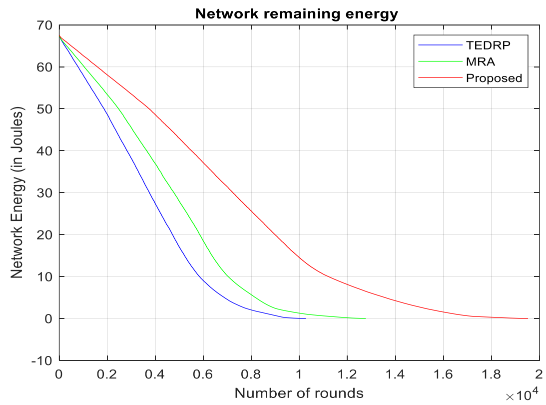

Fig. 6. Comparison of Network's Energy of IMRA with MRA, TEDRP

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k: Fraction of super nodes
h: Fraction of advance nodes
δ: Value that signifies the amount of time, the super node is higher in energy than normal nodes
ϵ: Value that signifies the amount of time, the advance node is higher in energy than normal nodes.
Table-II. Comparison of Improved MRA against other protocol with respect to network's remaining energy

REMAINING ENERGY (%)	**ROUNDS COVERED**		
	TEDRP	***MRA***	***IMPROVED MRA***
50	3502	4337	6571
20	5379	6536	10210
0	10179	12663	19443

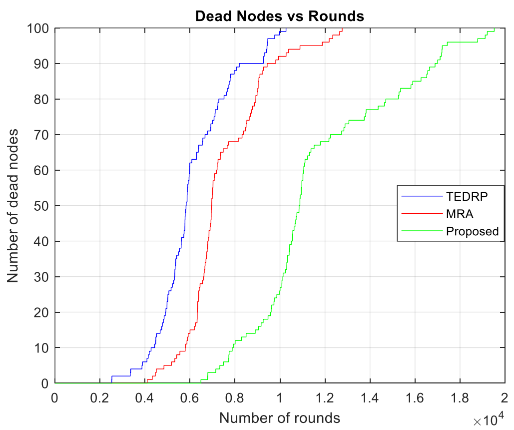

Fig. 7. Comparing Network's Lifetime for IMRA, MRA, TEDRP

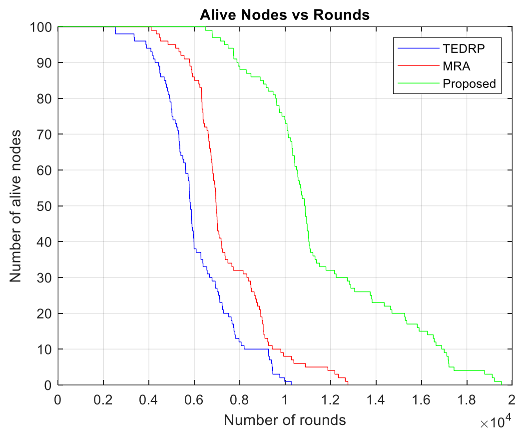

Fig. 8. Alive energy nodes vs rounds graph for comparison of IMRA, MRA, TEDRP

The IMRA is better than TEDRP, MRA in all parameters(network lifetime, HND, network remaining energy, stability period(SP)). The results are shown in Table3 and demonstrated using Figure8. SP of recommended protocol is ameliorated than MRA and TEDRP by 58.18% and 156.99% respectively. Better stability period signifies more reliable network. HND period is improved than MRA and TEDRP by 55.94% and 86.2% respectively. The network lifetime is improved than MRA and TEDRP by 52.96% and 90.12% respectively.

Table- III: Comparison of Proposed Protocol against other's in term of Network Lifetime, Half Node Dead and Stability Period

PROTOCOLS	**STABILITY PERIOD**		**HALF NODE DEAD(HND)**		**NETWORK LIFETIME**	
	ROUNDS	**%IMPR**	**ROUNDS**	**%IMPR**	**ROUNDS**	**%IMPR**
IMPROVED MRA	6484	-	10850	-	19522	-
MRA	4099	58.18	6958	55.94	12763	52.96
TEDRP	2523	156.99	5827	86.2	10268	90.12

k=0.2,h=0.3, δ=1, ϵ=0.5; "%IMPR" is Percentage Improvement

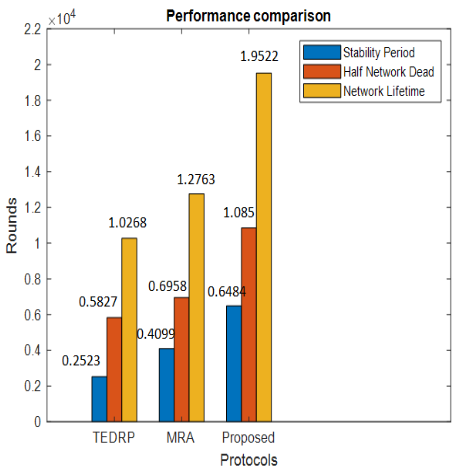

Fig. 9. Performance comparison of Proposed Improved MRA against other protocols

VII. CONCLUSION

Proposed Improved MRA performs better than traditional MRA and TEDRP due to additional parameters of load balancing and network's average energy. With owe to heterogeneity of network, the higher energy nodes deplete their energy sooner due to their higher probability to become cluster head. This causes hotspot problem and wastes network energy. Load balancing helps solve this problem by balancing the load among all nodes equally. The stability period of improved MRA is ameliorated than MRA and TEDRP by 58.18% and 156.99% respectively. Better stability period signifies more reliable network. HND period is improved than MRA and TEDRP by 55.94% and 86.2% respectively. The network lifetime is improved than MRA, TEDRP by 52.96% and 90.12% respectively. Since IMRA is event-driven protocol, it can be well suited for applications in severe environments like earthquake-prone areas, volcanic regions, wildlife monitoring etc. which are critical issues. More work can be implemented in future on security aspect of the proposed protocol and incorporating mobility in MGNs.

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