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A Refined Integrated MAC and Routing Protocol with Quantification Algorithm to Mitigate Hotspot Problems in Wireless Sensor Networks

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Abstract

Background: Wireless Sensor Networks (WSN) is an interconnected connection of two or more sensor nodes. A typical sensor node can perform Sensing, Computing and Communication. **Objective**: The core objective of this paper is to mitigate or to reduce the impact of the Hotspot effect in Wireless Sensor Network (WSN) by using a refined integrated MAC and Routing protocol and a quantification algorithm. **Methods/Analysis**: We are using a refined integrated MAC and routing protocol which divides the network into tiers. We also propose a quantification algorithm, which decides the optimum number of nodes in each tier to mitigate the hot-spot problem. The work is simulated in NS2. **Findings**: We simulated our work in NS2 and found that the proposed quantification algorithm along with Refined Integrated MAC and Routing Protocol outperforms SMAC in terms of network lifetime. **Conclusion**: The proposed protocol along with quantification algorithm increases the network life time and reduces the impact of the hotspot effect when compared with conventional MAC protocols.

Keywords: Hotspot Problem, Integrated MAC and Routing, Quantification Algorithm, Sink, WSN

1. Introduction

The advances in Micro Electro Mechanical Systems (MEMS) and wireless communication technologies have promoted the development of wireless sensor networks. A WSN consists of many sensor nodes densely deployed in a field: individually able to collect environmental information and together able to support multihop ad hoc routing. WSNs provide an inexpensive and a convenient way to monitor the physical environments. With their environment-sensing capability WSNs can enrich human life in applications such as health care, building monitoring, and home security. Due to the advancement in MEMS and availability of low-cost sensor nodes lot of research is being conducted in Wireless Sensor Networks. The major issue, which most researches focus, is on energy consumption in WSN. One related issue is hot-spot problem.

2. Problem Definition

WSN uses a multi-hop communication pattern i.e. the sensor nodes will not send the sensed parameter directly to the sink: rather they are passed on to the sink in a hop by hop fashion. So the nodes closer to the sink have to communicate their own sensed data and should also relay data from the other nodes. Hence they deplete their energy quicker than the other nodes. As a result the network may get isolated. In this paper we integrate MAC and Routing and form a tier based architecture as pro-

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posed in [1] with some refinement. Since it is generally assumed that sensor nodes would become inexpensive a simple solution to this problem is to add supplementary nodes in the hot-spot area[2]. We are also proposing a quantification algorithm, which decides the effective or optimum number of nodes in each tier to maximize the network life time and to reduce or to mitigate the hot-spot effect.

3. Existing Protocols

Several differing solutions are proposed to mitigate hot-spot effect as specified in [2–7]. A clustering approach similar to LEACH with varying cluster head is proposed in [3] to mitigate hot-spot affect. A muti-hop and hierarchical multi-hop routing approach is used in [4] to mitigate the hot-spot effect. An analysis of intelligent power control i.e nodes far away from sink should transmit over a longer distance and data aggregation using aggregator node to mitigate hot-spot effect is discussed in[5]. DEAR[6] algorithm optimizes each individual distance so that all sensor nodes consume their energy at a similar rate. Mobile sensors are used in[7] for surveillance. Besides mobile sensors nodes may self configure as-well for mitigation of hot-spot effect. Studies in [8] discusses the implementation of smart sleep mechanism and hybrid data collection technique for maximizing Network Lifetime in WSN's. Studies in [9] focuses on survey of various MAC protocols that consumes lesser energy by using dynamic clustering techniques and routing protocols that are used to achieve energy efficient and QoS data gathering. [10] Proposes a Cluster Based Multipath Dynamic Routing (CBDR) protocol for Wireless Sensor Networks which provides energy efficiency with better quality of service.

4. Proposed Work

The proposed work is divided into four parts namely 4.1) Tier-formation 4.2) Quantification Algorithm 4.3) Pseudo code of the proposed algorithm 4.4) Mathematical Representation for calculation of Energy Consumption and Network Lifetime.

4.1 Tier-Formation

To create tiers, we are following the approach similar to 1 with additional refinement. We divide the nodes around the sink as tiers. The nodes closer to the sink (eg. Within a range of 250m) form tier[1]. The next level of nodes (eg. which have a range of distance between 250m and 500m) form tier[2]. It follows the same calculation of the range of distance for the rest of the tiers. Tier formation consists of two phases namely i) Setup Phase and ii) Action Phase.

4.1.1 Setup Phase

Initially all nodes except the sink node's tier id will be set as -1 and the tier id of sink will be 0. The sink will broadcast a Hello Message with its tier id (i.e 0), the nodes receiving this message will set their tier id as 1 (i.e. received Hello Message tier id plus 1). Now all these nodes with tier id 1 will broadcast the Hello Message. The nodes with tier id -1 receiving this hello message will update their tier id to 2. This process continues until all nodes are assigned with a positive tier id. Thus the tier-formation will be completed.

4.1.2 Action Phase

If any node has to send a sensed data the node will broadcast an RTR message with its tier id.

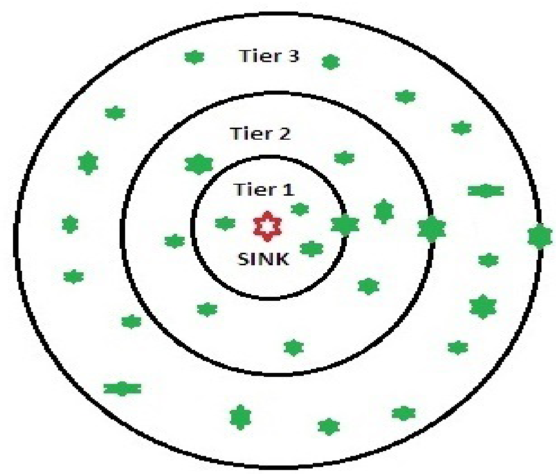

Figure 1. Tier Formation.

Unlike[1] all nodes in the previous tier receiving this RTR message (i.e the tier id of the receiving node should be 2 to send a CTR if the sender's tier id is 3) can respond with a CTR message. In contrary to 1 along with the CTR message the node will also send its current energy level. Upon receiving the CTR message from all the nodes the sender will unicast DATA packet to the node whose energy level is maximum. The receiver node would send an acknowledgment to the sender. Now, the receiver node will become the new sender and it will broadcast the RTR and transmit the data packet to the next tier. This process continues until the DATA packet successfully reaches the sink. The intrinsic nature of communication in a WSN is from node to sink and not from node to node.

4.2 Quantification Algorithm

Before, discussing the quantification algorithm, consider the following example.

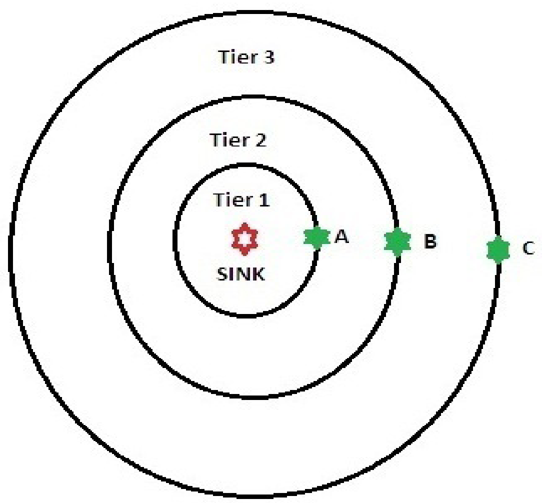

Figure 2. Hotspot Problem.

In Figure 2 there are three nodes A, B and C in the tier 1, 2 and 3 respectively. Let us assume that all the three nodes have an initial energy level of 5 joules and let us also assume that for every communication the node loses 1 joule of energy. At a given instance of time if all three nodes would like to communicate a sensed parameter to the sink node C will communicate the sensed data to node B in concurrence with the tier-based multi-hop communication. Now node C's available energy will be 4 joules. Node B has to communicate its own data besides the data from C, so its energy will become 3 joules and node A has to communicate its own data besides communicating two data from B. So its energy will be 2 joules. At the end of cycle 1 node A's energy will be 2 joules, node B's energy will be 3 joule and node C's energy will be 4 joule.

Consider the same action for cycle 2, i.e at a particular time instance all three nodes would like to communicate the sensed parameter to the sink. Now, after C's communication, its energy will be 3 joule and after B communicating its own sensed data and data from C, its energy will be 1 joule and A's available energy is only 2 joule, but it has to transmit 3 data, whereas It can communicate only 2 data and after that node A will be drained and as result hotspot occurs and the network gets isolated.

We are proposing a simple quantification algorithm by analyzing the above stated problem. The quantification algorithm is as follows.

If there are 'x' nodes in outer tier then there should be '2x' nodes in the next inner tier and '3x' nodes in the next inner tier and so on and there should be 'nx' nodes in the first tier, where 'n' is the total number of tiers. Applying this quantification algorithm to the problem stated in Figure 2, we will get a setup as follows.

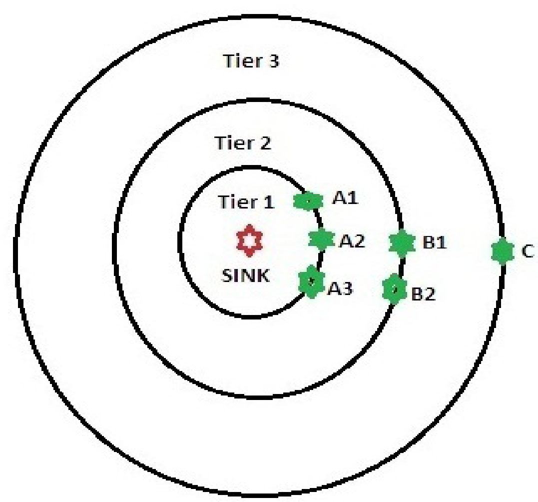

Figure 3. Quantification Algorithm Based Node Allocation.

Now, consider the situation that one node from each tier would like to communicate at a given instance of time and also let us assume that the initial energy of all nodes is 5 joules. Let us also assume that nodes B1 and B2 are in the same sensing range within tier2 and A1, A2 and A3 are in the same sensing range within tier2. Now during cycle 1 node C is sending a sensed data to tier2(let us assume to B1) and C's energy will become 4 joule. And meanwhile if any event occurs at tier2 then B2 will communicate that to tier1 as B1 is communicating with C and following which B1 will also communicate the data to tier1. Now the energy of B1 and B2 will be 4 joule. Assume the data send by B1 and B2 are received by A1 and A2 in tier 1 respectively, then A1 and A2 will communicate this data to the sink. Meanwhile if there is any event at tier1 this will be communicated by the node A3. So, by the end of cycle 1 all nodes A1, A2, A3, B1, B2 and C have energy level of 4 joules. And if this continues at the end of cycle 5 all nodes energy will be 0. It should be noted here that the events occur rarely in a WSN, what we have considered here is a worst-case scenario to produce a model for maximizing the life time of WSN. Compared to the basic model proposed in Figure 2, the model proposed in Figure 3 increases the lifetime by 4 fold, which is a substantial improvement. The quantification algorithm can be defined as follows, given the number of Nodes (N).

$nx + (n-1)x + ...+ 2x + 1x = N \rightarrow A$

where 'x' is the number of nodes in tier-n and 'nx' is the number of nodes in tier1.

'x' can be calculated as follows

From 1, we know that the area of Tier-n is

$$A(Tn) = \pi(2n-1)(\alpha R)^2 \rightarrow B$$

$$\text{So, } x = \pi(2n-1)(\alpha R)^2 / TR_{range} \rightarrow C$$

Where, TR_{range}, is the Transmission range of each sensor nodes in Sq.m.

4.3 Pseudo Code of the Proposed Algorithm

The objective of the proposed work is to minimize the impact of the Hotspot and thereby to increase the network lifetime. The network lifetime is defined as the time at which the first node dies. Here, we provide a pseudo code to calculate the network life time.

Step 1:

i. Create set of Sensor nodes 'S_i'. {i ranges from 1 to n}

ii. Initialize Timer.

iii. Time = Current Time.

Step 2:

Initialize energy for all sensor nodes as $E(S_i) = IE$, where 'IE' represents 'Initial Energy' in joules.

Step 3:

While (No_Event_Sensed_For_Node_i)

{

1. If sensor node 'S_i' sensed a event, go to Step 4.

}

Step 4:

If $E(S_i) > E_{thresh}$

Si broadcasts RTR with its tier-id.

Else

Network Life Time = Current Time

Exit (0)

Step 5: Set of sensor nodes, say 'S_x', where 'x' ranging from 1 to k, in the previous tier which are not communicating and which receives the RTR can respond CTR along with node energy level.

If $E(S_x) > E_{thresh}$

S_x = SEND (CTR, S_i) //S_x Sends CTR to Si

Else

Network Life Time = Current Time

Exit (0)

Step 6: S_r = MAX_ENERGY (S_x) //S_i finds the node with maximum energy level.

If E (Si) > E_{thresh}

S_i = SEND (DATA, S_r) //S_i sends DATA to S_r

Else

Network Life Time = Current Time

Exit (0)

Step 7: If $E(S_r) > E_{thresh}$

S_r = RECV (DATA, S_i)//S_r recv DATA from S_i

Else

Network Life Time = Current Time

Exit (0)

If e $(S_r) > E_{thresh}$

S_r = SEND (ACK, S_i)//S_r sends ACK to S_i.

Else

Network Life Time = Current Time

Exit (0)

Step 8: If $e(S_i) > E_{thresh}$

S_i = RECV (ACK, S_r)//S_i recv ACK from S_r.

Else

Network Life Time = Current Time

Exit (0)

Step 9: $S_i = S_r$ // S_r is the new S_i.

Repeat Step 4 to Step 8 until DATA reaches Ssink. The Network Lifetime will be available in the variable Network Life Time.

4.4 Mathematical Representation for Calculation of Energy Consumption and Network Lifetime

i. Let the set of sensor nodes is represented as $S_i\{S_1, S_2 \ldots . S_n\}$.
ii. Let the Initial Energy (IE) of all nodes as $E(S_z)$ = IE.
iii. The energy consumed during transmission of a packet by any node 'w' is given by.

$E_t(S_w)$ = et * packet_size. → (1)

iv. The energy consumed during receiving.

$E_r(S_w)$ = er * packet_size → (2)

Step 1:

If node 'S_i' senses an event, it broadcast an RTR Packet, then the energy consumed at node 'S_i' is given by.

$E(S_i)$ = $E(S_i)$ – [et * PKT_SIZE (RTR)] → (3)

Step 2:

If a set of nodes say 'Sx'{ where 'x' ranges from 1 to k} receives the RTR packet, then the energy consumed by these nodes are given by.

$E(S_x)$ = $E(S_x)$ – [er * SIZE (RTR)] → (4)

1 <=x<=k

Step 3:

Let 'Sy' be the set of nodes in the previous tier responds with a CTR along with the energy level to node 'S_i', then the energy consumed by these nodes is given by.

E(Sy) = E(Sy) – [et*SIZE(CTR)] → (5)

1<=y<=l

Step 4:

After receiving the CTR from all the nodes, node 'i' identifies the node with maximum energy level and unicasts DATA packet to this node. Let the node with maximum energy represented as S_{emax}.

Now, the energy consumed by node 'i' is given as.

$E(S_i)$ = $E(S_i)$ – [et * SIZE (DATA)] → (6)

Step 5:

After successful reception of this packet, the energy consumed by node S_{emax} will be.

$E(S_{emax})$ = $E(S_{emax})$ – [er * SIZE (DATA)] → (7)

Step 6:

Now, sensor node 'S_{emax}' will send ACK and sensor node 'S_i" will receive ACK, so the energy consumption is given as.

$E(S_{emax})$ = $E(S_{emax})$ – [et*SIZE(ACK)] → (8)

$E(S_i)$ = $E(S_i)$ – [er * SIZE(ACK)] → (9)

Now, sensor node 'S_{emax}' will become sensor node 'S_i' and the above set of steps will repeat, till the DATA reaches SINK.

Energy consumed by a node 'S_i' for one successful transmission of a DATA packet is given by.

$E_{tr}(S_i)$ = et*SIZE(RTR) + y*er*SIZE(CTR) + et*SIZE(DATA) + er*SIZE(ACK) → (10)

Energy consumed by a node 'S_i' for successfully receiving one DATA packet is given by.

$E_{rc}(S_i)$ = er*SIZE(RTR) + et*SIZE(CTR) + er*SIZE(DATA) + et*SIZE(DATA) → (11)

Before every transmission and reception, every sensor node 'S_i' should ensure that the energy level of the node is greater than the Threshold energy level. This is given as

If($E(S_i)$ < $E_{threshold}$)

Network_Life_Time = Current_Time

5. Simulation and Experimental Results

We have made a Simulation with three scenarios, each having three tiers. In Scenario 1(Figure 4) there are 4 nodes in each tier, in Scenario 2 (Figure 5) there are 8

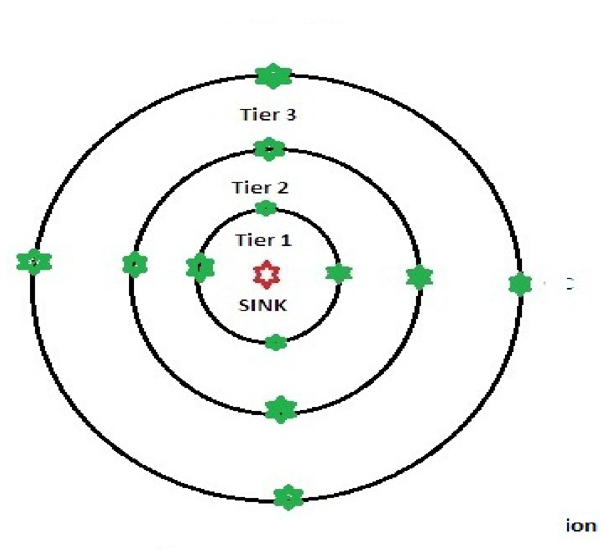

Figure 4. Scenario 1.

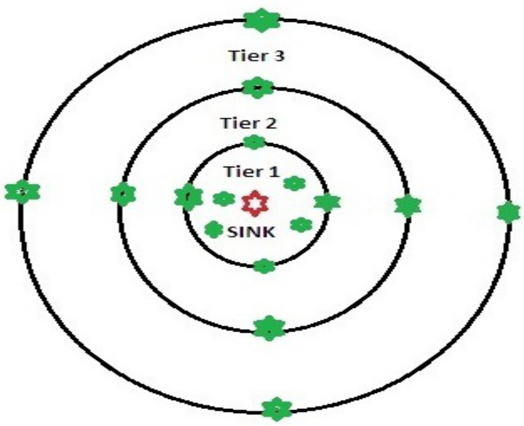

Figure 5. Scenario 2.

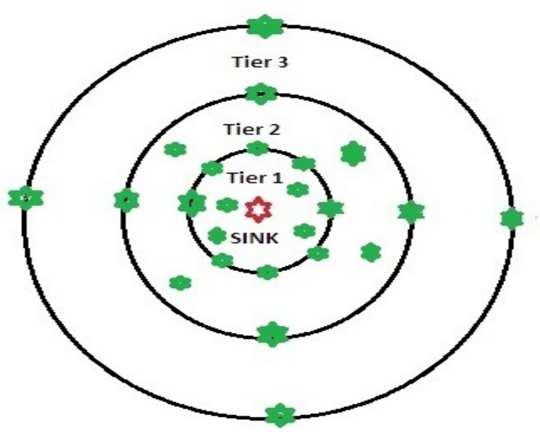

Figure 6. Scenario 3.

nodes in first tier and 4 nodes in other two tiers and in Scenario 3 (Figure 6) there are 12 nodes in first tier, 8 nodes in the second tier and 4 nodes in the last or third tier following the quantification algorithm. These three scenarios have been simulated with SMAC and Integrated MAC and routing algorithm. Each scenario is executed for more than 20 times. Randomly a node is chosen for communication. The values plotted in the graph are the average values of this simulation result. Scenario 3 is the full implementation of quantification algorithm. From simulation results it has been found that Scenario 3 outperforms Scenario 1 and Scenario 2 and also it has been

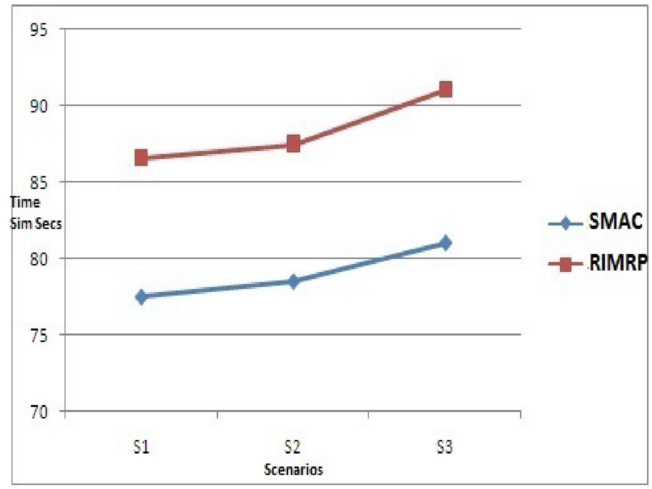

Figure 7. SMAC Vs. Refined Integrated MAC and Routing Protocol (RIMRP).

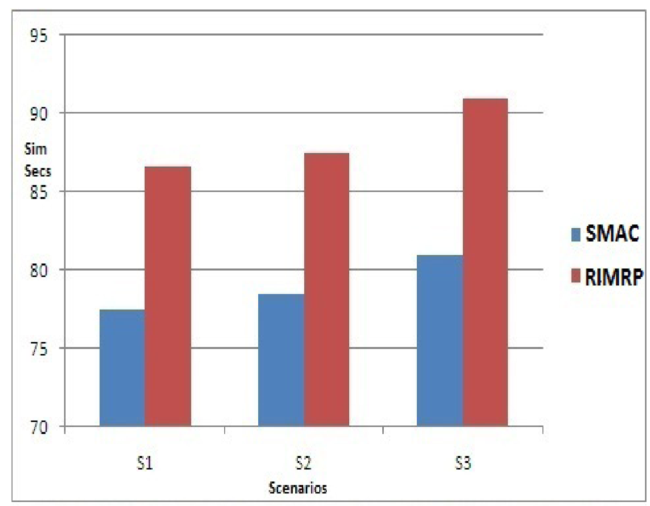

Figure 8. SMAC Vs RIMRP.

found that Tier based quantification gives better network life time for refined Integrated MAC and Routing algorithm than SMAC.

From the Figure 7 and 8, we can observe a substantial improvement of overall lifetime of the network for refined Integrated MAC and Routing protocol.

6. Conclusion and Future Scope

We have addressed the Hotspot problem in WSN and proposed a simple and efficient algorithm to mitigate the Hotspot effect and to improve the overall network lifetime. The paper can be further improved by working on the lines of deciding the number of sensors nodes in each tier given a coverage area and for simplicity we have not considered the sleep/wake-up pattern, by considering the sleep wake-up pattern, the effective number of nodes in each tier may still increase but as the sensor nodes are getting cheaper and cheaper it may not be an hindrance. The solution proposed is a trade-off between number of sensor nodes in each tier and the overall life-time of the WSN.

7. Acknowledgement

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8. References

1. Kulkarni S, Iyer A, Rosenberg C. An Address-Light, Integrated MAC and Routing Protocol for Wireless Sensor Networks. IEEE/ACM Transactions on Networking. 2006 Aug; 14(4):793–806.
2. Rivas H, Voigt T, Dunkels A. A simple and efficient method to mitigate the hot spot problem in wireless sensor networks. Performance Control in Wireless Sensor Networks; 2006 May; Coimbra, Portugal.
3. Mao YE, Chan E, Chen G. On mitigating hot spots for clustering mechanisms in wireless sensor networks. National Laboratory of Novel Software Technology; p. 558–61.
4. Abdulla AEAA, Nishiyama H, Kato N. Extending the Lifetime of Wireless Sensor Networks: A Hybrid Routing Algorithm. Computer Communications. 2012 May; 35(9):1056–63.
5. Perillo M, Cheng Z, Heinzelman W. An Analysis of Strategies for Mitigating the Sensor Network Hot Spot Problem. The Second Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services. 2005. MobiQuitous; 2005 Jul 17-21. p. 474–8.
6. Wang J, de Dieu IJ, De Leon Diego Jose A, Lee S, Lee YK. Prolonging the Lifetime of Wireless Sensor Networks via Hotspot Analysis. 2010 10th IEEE/IPSJ International Symposium on Applications and the Internet (SAINT); 2010 Jul 19-23; p. 383–6.
7. Tseng Y-C, Wang Y-C, Cheng K-Y, Hsieh Y-Y. iMouse: An Integrated Mobile Surveillance and Wireless Sensor System. IEEE Computer Society. 2007; 40(6):60–6.
8. Shankar T, Karthikeyan A, Sivasankar P, Neha RR. Implementation of Smart Sleep Mechanism and Hybrid Data Collection Technique for Maximizing Network Lifetime in WSN's. Indian Journal of Science and Technology. 2015 May; 8(S9):1–8.
9. Kumar SA, Ilango P. Data funneling in wireless sensor networks: a comparative study. Indian Journal of Science and Technology. 2015 Mar; 8(5):472–80.
10. Varma GNSA, Reddy GAK, Theja YR, Arunkumar T. Cluster Based Multipath Dynamic Routing (CBDR) Protocol for Wireless Sensor Networks. Indian Journal of Science and Technology. 2015 Jan; 8(S2):17–22.