ROMANIAN JOURNAL OF INFORMATION SCIENCE AND TECHNOLOGY
Volume **24**, Number 3, 2021, 284–298

A Novel Layer By Layer Energy Efficient Watchman Algorithm for Wireless Sensor and Actor Networks

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Abstract. In this paper, a novel layer-by-layer Energy Efficient Mobility-Based Watchman Algorithm (E2-MBWA) is introduced to increase the network lifetime by reducing the hotspot issue in wireless sensor and actor networks. Typically, WSAN networks are deployed to monitor physical objects or environmental conditions such as pressure, temperature, and sound, etc. Due to the high consumption of energy, nodes become dead early, these dead nodes cause to isolate some parts of the network. Therefore, the power management of such a network is highly complex. The limited power resources in the network are caused of the Hotspot problem. Due to the Hotspot issue in the network, limited network lifetime, unnecessary delay, data packet losses, throughput and end-to-end delay are mostly affected. Therefore, it is required to design a new algorithm that resolves these issues efficiently. In this approach, watchman nodes are introduced and sub-algorithm like the Watchman Nodes Assigning algorithm (WNAA). In addition, the proposed algorithm is provided alternative data storage (when a neighboring node of the sink is going to die) in the form of the Watchman Secondary Nodes Algorithm (WSNA). Energy consumption, end-to-end delay, and throughput are considered for the evaluation of the proposed algorithm. At the end, the proposed algorithm is compared with an existing state-of-the-art algorithm like the Efficient Traffic Load Reduction Algorithm (ETLRA) that also works with limbs node for the said problem in the same kind of wireless environment.

Key-words: Hotspot, Throughput, Energy, sensor/Actor, Watchman Algorithm, ETLRA, WNAA, WSNA.

1. Introduction

Everyone knows the magnificent advancement in the field of communication and information technology. Wireless communication is successfully replacing the wired medium with the help of sensors, actors and a combination of them. The existing wireless sensor and actor networks (WSANs) play a key role in many areas and real time environments. For example, transportation, construction, mineral finding and food resources, oil and water industry, battlefield environment and defense system, aviation department and Mobile Area Networks (MANETs) [1–3]. Due to these reasons and the number of applications, this field gains attraction among all research fields. Sensors basically sensing the informative task from the outside world and actors take appropriate action on the information that are provided by sensors. This is because; the Sensors-Actors Communication (S/A) and coordination have strong bonding to tackle any issue inside the network. It also has been observed that the deployment strategy might be different in underwater and terrestrial environments, but the working order is the same [4, 5]. For example, Firstly, the size of the network is different for the different environment against the particular application, see this [6]. Furthermore, the number of nodes determines the size of the network, as the quantity of nodes increase, size, cost and other realistic parameters are increased. Secondly, the amount of energy that will be used to prolong the lifetime of the network is also affected by the size of the network too. The fundamental concerns of WSAN are to maintain the Sensor-Actor communication in order to maximize the throughput, end-to-end communication/delay, and network lifetime. In addition, to calculate the energy, by mean energy of the nodes, sink nodes, ordinary nodes and sink-neighboring nodes that have the responsibility to maintain the communication from source to sink, is difficult. WSANs need different types of novel technique and approach that works efficiently in any type of network like stable/unstable and dynamic/static environment [7].

1.1. Network Structure

In WSANs, all nods are randomly deployed in some static and dynamic fashion. The whole network consists of three major sections like ordinary nodes (that used to send the data from source to sink), sink-neighboring nodes (that are close to sink and bear the complete traffic of the network), and sensor-actor nodes (responsible to intra-communication). All these three sections of the network are being responsible for communication, transportation, packets movement and delivery, sending and receiving acknowledgments [8] For a time being, if any one of the section of nodes working stops, the whole network is isolated also called hotspot problem [26, 27, 29]. Solution for an isolated network and maintain the flow of communication needs efficient techniques and algorithms that can understand and operate the nature of WSAN in a prime disciplined manner. The overall conceptual view of the hotspot networks is presented in fig 1.

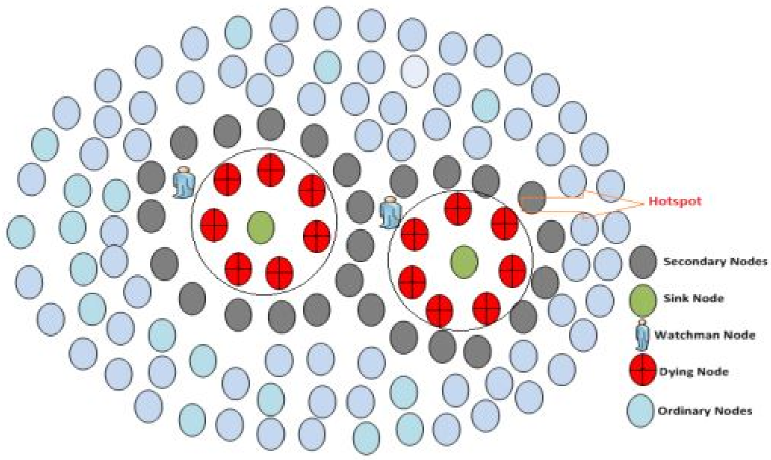

Fig. 1. Conceptual view of hotspot and deployment of watchman node to rescue the Hotspot problem.

2. Layer by layer Division of ordinary Nodes, Sink Nodes, Watchman Nodes and layers inside the sensor and actor nodes

All nodes that are used in this research work are deployed from several levels in random order; in a novel layer-by-layer hierarchy. The total number of nodes will decide the number of watchman nodes. If the total numbers of nodes are 500 then 5 watchman nodes is enough to handle this amount. Every node has ID for its identification and exchanges the communication, in the form of "Hello Packets". The deployment of nodes adopts layer-by-layer topology in order to transmit the packets from source to sink. Hence total number of nodes 500 are deployed in 5 layers, Watchman nodes are calculated from the formula below:

$$\text{No. of Watchman Nodes} = \frac{\sum \text{Total number of nodes}}{\sum \text{Total number of nodes in one layer}}.$$

The major advantage of using a layer-by-layer strategy is that every node takes the data from the previous layer and forwards to the next one. In this case, every watchman node easily monitors and investigates the hotspot issue. Furthermore, the mobile property is coped with watchman that have an extra amount of energy is considered (this is the only consideration for simulated work).

The deployment mechanism of sensor nodes in the form of layers from the surface to the source is adopted. The layer-by-layer strategy initially helps to control and monitor the movements of nodes in the network, but the overall network is in a random fashion as discussed in equations 1 to 5 provide the procedure to decide the total number of nodes in a layer, sink nodes and the total number of layers in the network from source to sink.

$$\begin{aligned} No.\,of\ 1st\ layer &= L_1(ON)_1 \\ No.\,of\ 2nd\ layer &= L_2(ON)_2 \\ &. \\ &. \\ &. \\ No.\,of\ nth\ layer &= L_n(ON)_2 \end{aligned} \tag{1}$$

Sum of all equations

$$No.\,of\ nodes = L_1(ON)_1 + L_2(ON)_2 + ... + L_n(ON)_n \tag{2}$$

Apply summations

$$\sum_{i=0}^{n}(ON)_i = \sum_{i=0}^{n} L_i(ON)_i \tag{3}$$

Where, the total number of ordinary nodes are considered 500.

$$\begin{aligned} For\ 1st\ layer_{1-s}\ (towrds\ the\ sink) &= 100 \\ For\ 2nd\ layer_{2-s}\ (towrds\ the\ sink) &= 100 \end{aligned}$$

By assigning equal no. of nodes each layer; the possible equation is:

$$No.\,of\ nodes = \frac{(TN)_n}{1 - \frac{1-s}{(TN)_n}} \tag{4}$$

$$No.\,of\ nodes = \frac{500}{1 - \frac{1-500}{500}}$$

$$No.\,of\ nodes = \frac{500}{\frac{100}{500}}$$

$$No.\,of\ nodes = 100.$$

Similarly, for all remaining nodes like 400, 300, 200 and 100. To decide the Sink-neighboring nodes (SNN) around the sink, let take an extension from equation 4. By and large, the SNN anyhow is evaluated from the total number of nodes. Let it be considered that by using multi-sink architecture, a possible number of sinks can be retrieved, such as in equation 5.

$$No.\,of\ sink(NoS) = \sum_{0}^{n} \frac{(TN)_n}{(L_n)_n} \tag{5}$$

$$\begin{aligned} No.\,of\ sink(NoS) &= \frac{500}{100} \\ No.\,of\ sink(NoS) &= 5sinks \end{aligned}$$

It is important to note that number of layers doesn't depend upon the overall performance of the network as its advantages as [12–15]. Furthermore, if the number of layers increased in some exponential function then the number of sinks also increased, and the cost of the network also increased. Distance between layers is enough so that one Watchman node is easily accommodating between two layers. In the case of the mobility of nodes layout of the whole network is not distributed. 100 m transmission is decided for the nodes between the layers that will be used for maximum throughput. In special cases, all nodes have enough capability to increase the transmission range, but this is only one consideration that needs to be those situations where traffic of the network is increased [16-18].

3. Energy-Efficient Mobility-Based Watchman Algorithm (E2-MBWA)

A novel approach to investigate the Hotspot issue is the Energy-Efficient Mobility-Based Watchman Algorithm (E2-MBWA) is proposed in this research work. E2-MBWA is basically energy efficient related to Hotspot issue and mobility-based property for mobile nodes. It is the best practice to tackle the movement of mobile nodes, the Watchman Node (WMN) also should be movable that have an extra amount of energy as compared to other ordinary nodes that is the main difference of WMN and ordinary nodes. In order to the successful transmission of data packets between source and sink, multiple sink architecture is used but at a fixed position [9–11]. For the sake of experiment, to play the role of Energy-Efficient Watchman Nodes (E2-WMN), initially defined specific simulated area is used, but anyhow to take the undefined area or unbounded environment where the number of nodes is not fixed than multiple sink strategy plays our role. For our work, two or more than two, sinks are involved to handle and receive the traffic from source to base station. Two types of dedicated environments can be handled by the proposed algorithm like static and dynamic environments.

3.1. Assigning IDs

Assigning IDs to the Ordinary Nodes (ON) and Sink Neighboring Nodes (SNN) (inside the sink zone (SZ)) is the major task of the proposed algorithm. In the dynamic WSAN environment, there is mandatory to assign ID to each node. In this way smooth and credible communication is easily performed as our deployed network mostly consists of a number of sensors/actors, SNN, ON within a defined layer, so that four different categories in which assigning ID is confirmed.

Ordinary nodes ID: ONs are frequently present inside the network so assigning IDs of ON is unique and peculiar; so that sink or base station is easily recognized.

Sink-neighboring nodes ID: After assigning the ID to ordinary nodes, the sink-neighboring nodes can also be said ON, it is because of; indeed, the nodes are closer to sink, that's why called sink-neighboring nodes. SNN has fixed number of IDs because all the nodes don't more enough and always keep around the sink as compared to ON ones.

Sink or layer zone (SZ or LZ): In order to accomplish the network task and increase its capability for the best understanding of the reader, even then non-specialist reader, the sink zone or layer zone has been categorized accordingly. All the nodes inside the network are usually deployed in a fixed layer so that SZ and LZ also have a unique ID, this is not changed. However, it can change the IDs; according to run-time requirements.

Layer ID: It has a unique ID from source to sink. Each layer consists of a number of ON and defined SNN. So, for the sake of smooth communication layer ID play our role.

3.2. Watchman Node Assigning Algorithm (WNAA)

The total number of nodes (including SNN and WMN itself) that are deployed and considered for this research work is 500 (sufficient to deploy the medium scale network in NS-2). All these nodes that equally distributed in the form of layers are deployed. For the best understanding and not increase the complexity of the network, the number of layers is must be equal to the watchman nodes (in order to make a uniform environment).

If the total number of nodes is 500, the total number of layers and WMN is 5. By using multi-sink architecture, every layer does not only consist of WMN but also one sink, several SNN and a number of ON. All ON gathered the SNN around the sink and WMN also deploy around the sink, it is because of; Hotspot issue mostly occurs around the sink, (When SNN suffer all traffic from ON). In order to check the status of all nodes, (SNN, ON, WMN) in terms of energy resource, nodes are alive and have an active sink or base station that floods the 'Hello packets (HP)' every 40 minutes. The only nodes that is called SNN have a fixed ID that is one'1' ON have lot of quantity, therefore random ID are assigned that is"11". The role of watchman nodes (WMN) is appreciated and provides the rescue environment inside the network, therefore the ID that is assigned to WMN="111". By counting maximum layer and watchman nodes, it initializes with a counter; and the maximum number of layers and WMN for 500 nodes is divided into 5 layers with 5 WM are enough to monitor the network. (Formula is previously discussed for this best of division).

However, it is not mandatory for this value of layers and watchman; it can be increased or decreased with the size of networks. As our proposed simulation environment consists of dynamic topology by the area of $1200 * 600 * 600$ square meters, so 500 nodes are fixed to accommodate this mentioned area. No more room is for taking extra nodes, that is the justification of the number of WMN and layers. After counting both; by mean WMN and number of layers, initially, it can be declared with a counter value is 1.

If Hello Packet-Acknowledgement (HPA) is received from all ordinary nodes and the maximum number of layers and watchman is less than the defined value, then all the corresponding ON-ID and WMN-ID are successfully assigned. So, in this case, every layer and watchman node get ID. In another case of the above condition is not true and layer-ID and WMN-ID is below its initialize limit than discard HPA, current value of layer and WMN-ID is automatically assigned to them and increment with the value of 1 and will make a decrement of 1 in max-layer and WMN-counter, this process continues until unless when both counters is equal to zero, then broadcast would be stop and this process repeat again. Watchman Node Assigning Algorithm (WNAA) "Hello packet" broadcast every 40 minutes and wait for acknowledgment from all SNN with fixed-1D "1" received HPA.

3.3. Watchman Secondary Nodes Algorithm (WSNA)

After successfully deploying the Watchman node near SNN in the form of layers. Every WM is coped with two or more than two secondary nodes to cover the boundary of the network area. We know that our network is deployed in the form of a layer with dynamic topology. The movement of ON is possible in all directions, but the movement of the node is appreciated with forwarding direction from the lower-to-upper layer. So, in this case; if the Hotspot occurs at the boundary of the network then the possible direction of dying nodes is left to right and up to down of the network. If the Hotspot occurs in the center of network, then there are two ways to rescue the network. The first way is left-right (L-R direction) and the other is up-down (U-D direction). If nodes are present in up and down positions, then layer numbers $1st$ and $3rd$ play our role that has separate WM Node. So, the justification for deployment of secondary nodes is the best suited with L-R positions. As a courtesy, the experiment of upward and diagonal data packet forwarding has successfully done in our previous article in [19–24].

	Algorithm 1: Watchman Node Assigning Algorithm (WNAA)
1.	Ordinary node-ID=11 // new node, when layer or sink-zone does it assign -1D than by default it will be "11"
2.	Number of Layer-count (LC) = 5 Number of WatchMan = 5
3.	L=1 WMN = 1 //initialization of WMN layer
4.	If (HPA =ON_ID); If $(L < LC)$; (WMN = No. of Layers) If (ON_ID = '11' and WMN = '111')
5.	Layer_ID= L and WMN = W // Every layer and WMN will get 10
6.	Else
7.	If (L_ID ≤L and $WMN \leq W$)
8.	Discard HPA
9.	Else
10.	OM_ID = "L" and WMN = "111"
11.	L++ and W++
12.	Continuously_Broadcast 'hp'
13.	End If
14.	End If
15.	End If
16.	LC = 5 and WMN = 5 // stop further broadcast
17.	No further broadcast from sink
18.	Exit

Each layer equipped with 100 ordinary nodes and two possible secondary nodes, many reasons behind this why two SNs are enough, one of them is, in case of hotspot occurring around the sink two SNs are enough to rescue that part of the network. However; the frequency of Hotspot occurrence can be increased or decreased. The secondary node will active only when 'HP' is sent from WMN. By initializing the ID of SN; by mean Left (L1) and Right (R1) are two possible positions of SN. If the WM is in layer-ID and the total number of secondary nodes are less than its quantity then L1 and R1 positioned are assign and SN gets the status of active, automatically. Once, SN gets the active status then they state to consume energy otherwise doesn't perform any activity in the network; until unless receiving an active massage from the watchman. Therefore; the luxury advantage is got by deploying the SN to rescue the network; not only rescue purpose but also prolong the lifetime of the network. This process will continue until unless all secondary nodes of all layers become active when Hotspot occurs. All this active status of SN of one or all layer of the network is dealing with caution.

4. Efficient Traffic Load Reduction Algorithm for Hotspot

The hotspot is a major issue that causes by unbalance amount of energy inside the network [25–29]. Basically; the reason for the creation of Hotspot is multiple query requests among nodes for the specific event and the network is called query-based network. As everyone knows about due to Hotspot unequal traffic lead around the sink neighboring nodes. In this case, the total amount of energy is also disturbed around the sink and the whole network is isolated [30]. For this Efficient Traffic Load Reduction Algorithm is discussed in this paper for comparison purposes.

Algorithm 2: Watchman Secondary Nodes Algorithm (WSNA)
Each layer has WM with two secondary nodes HP broadcast to secondary node to become active
For all SN have fixed_ID "L_1" and "R_1"
SN_ID = "L_1" and "R_1" // Possible position of SN
Maximum SN_Count (SNC) = 10 //total quantity of SN
J = 1 // initialize the SN
If ($WM == L\_ID$ Layer –Count and $j \leq Max.SN$)
If (SN_ID== L_1 and R_1)
L1 and R1 = j
SN_ID = Active
Else
If ($SN \leq SNC$)
Discard SN
j++
Broadcast HP by WM further
END IF
End if
Maximum SNC = 10 // Total No. of SN that cause to stop broadcasting.
Stop broadcast
Exit

In this algorithm, two types of sub-algorithm are discussed like for the agent selection. First, is distance based that measure occurrence, second is greedy based that further work with mobility-based node called limb node, that is responsible to move around the area where Hotspot is occurred. The major reason to equip the mobile agent-based nodes shifts our status to Hotspot nodes from limb node. In order to optimize the burden of traffic load limbs nodes play our role. By the help of DMAS and GMAS, the issue of Hotspot around sink-neighboring nodes is 50 percent effectively. By calculating Hotspot threshold value, the total number of nodes (neighboring nodes) can be divided by the traffic flow rate by average query.

$$\frac{\text{Traffic flow Rate}}{\text{Total Hotspot}} \geq \text{ Hotspot Thread}$$

$$\text{HT} \geq \text{ No. of nodes (neighnouring nodes).}$$

5. Simulation Environments

Network Simulator 2.3 version is used for the evaluation of E2-MBWA. As earliest describes the total number of nodes is 500 that is divided in 5 layers in such a way that each layer consists of 100 nodes in which both watchman, mobile nodes and Sink-neighboring nodes (dynamic) are deployed. Total simulated area of simulation is $1200x600x600$ square meters. Each layer consists of at least one sink and multiple numbers of ordinary nodes that help to maintain the flow of communication with radio communication capabilities. The total distance between layers of node at one layer to another is 50 meters. The main evaluation parameters that are analyzing the performance of the proposed algorithm is energy-consumption, end-to-end delay, throughput and network lifetime. In this case, any delay that is occurring from source to sink when all packets are successfully received is called End-to-end delay. Energy consumption can be defined as: measurement of energy at each node that is utilized to successfully send the data packets from source to sink called energy consumption of the nodes. In the whole network; every node plays its role to transmission and communication in such a way that the whole network doesn't isolate is called network lifetime. All these parameters and the proposed technique are designed through nam. animator file, tool command file, source file that is present inside the simulation tool.

6. Throughput, End-to-End delays and Energy consumption

Possible results of throughput are shown in fig 2 in which with and without Hotspot have two separate values. $(90 - 100)$percent throughput is achieved without Hotspot, because when all the number of packets successfully received of the destination node than throughput is gradually increased. Fig 3 discusses End-to-End delay against the presence and absence of Hotspot. With Hotspot, the delay is maximum, because the maximum number of nodes is isolated and loses their energy value. Bar graph is used to analyze the energy consumption of the network. A linear relationship between energy consumption (that is measured in Joule) and number of nodes is obtained. From fig 4 it has been seen clear without Hotspot; the consumption of energy as not much as decreased as in presence of Hotspot. However, energy-based performance analysis of several routing algorithms has been done in our last efforts in [20–24].

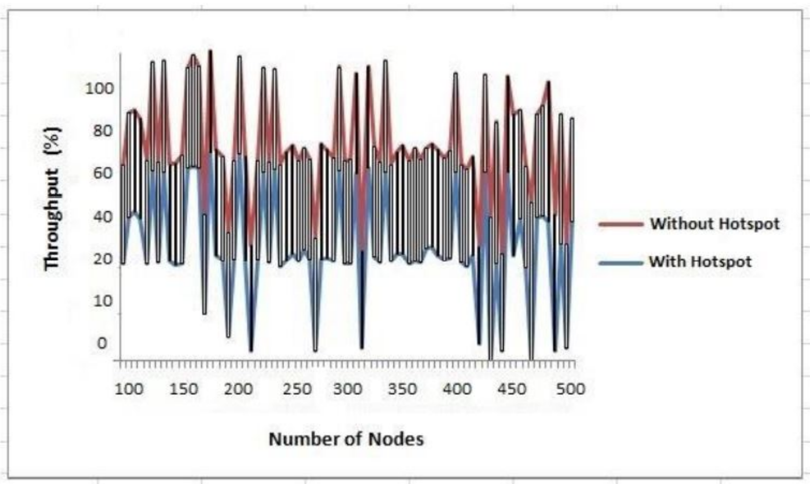

Fig. 2. Analysis of Throughput with and without Hotspot.

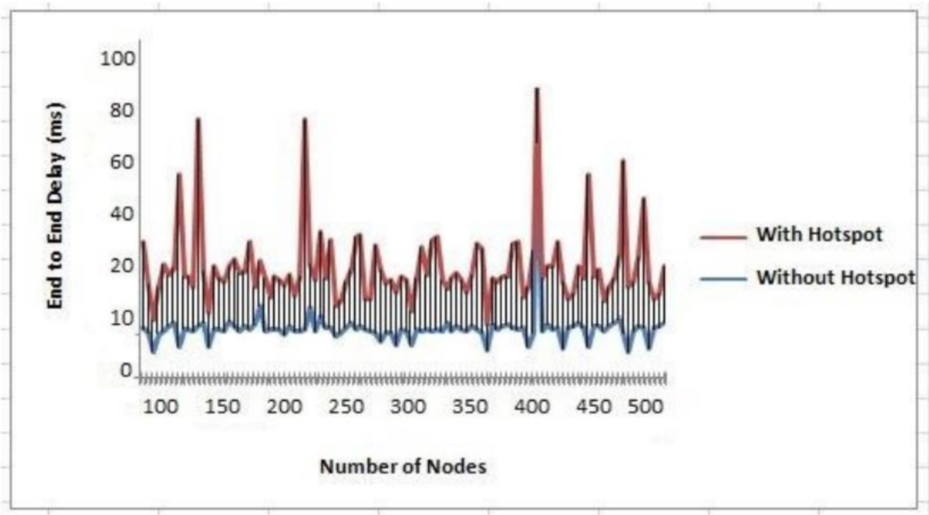

Fig. 3. Analysis of End-to-End Delay with and without Hotspot.

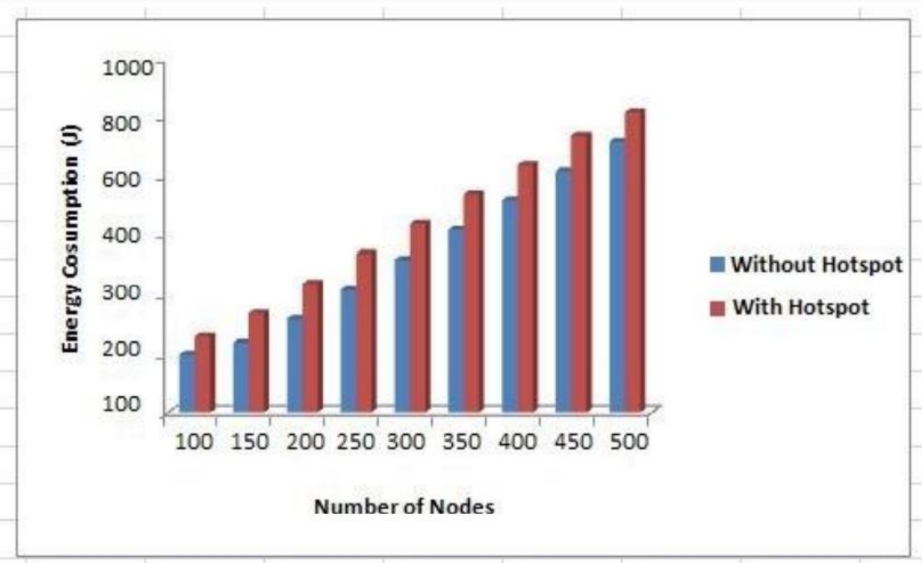

Fig. 4. Energy Consumption with and without Hotspot.

6.1. Effect of Network Lifetime

Network lifetime is calculated from the existence of the last node (if it is functional). It means unless when the last node is functional and plays our role for communication then life of the network is considered. Basically, network lifetime is directly based upon the number of nodes and their energy values. A directly proportional relationship exists between these two terms, as the number of nodes increase; network lifetime is also increased. Fig 5 display the network lifetime.

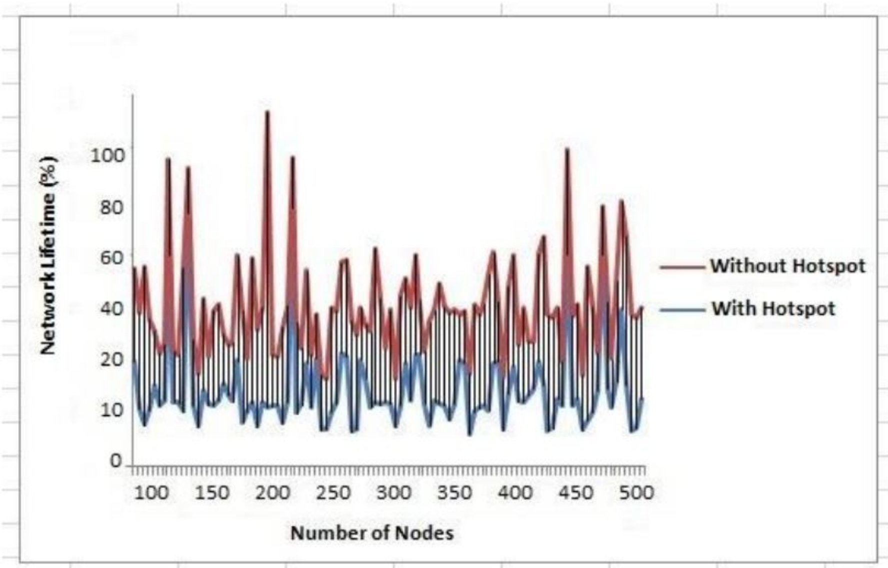

Fig. 5. Analysis of Network Lifetime with and without Hotspot.

7. Comparison with ETLRA and E2-MBWA Vs. End-to-End delay, throughput, Network Lifetime and traffic load

With E2-MBWA, end-to-end delay is measured in millisecond, for 500 numbers of nodes against various numbers of layers. ETLRA continuously increased the end-to-end delay as compared to E2-MBWA. As the number of nodes is increased end-to-end delay is increased and vice-versa. At the peak level of 500 numbers of nodes, the major difference is appeared up to 65percent to 82percent approximately. Fig 6 shows the end-to-end delay of both the compared and the proposed technique. Fig 7 shows that the throughput ratio (percent) of both techniques. In case of throughput measurement every time when iteration is complete the data is re-scheduled, so a millisecond delay occurs. Two types of traffic agents like TCP and UDP already used for maintaining the flow of traffic; some delays also occur in case of TCP because TCP used three way-handshake so many delays come in this type of communication. So, throughput is decreased at the receiver end. Fig 8 shows the network lifetime ratio. Fig 9 shows the traffic load ratio of the well-known technique of efficient traffic load ratio vs. the proposed technique.

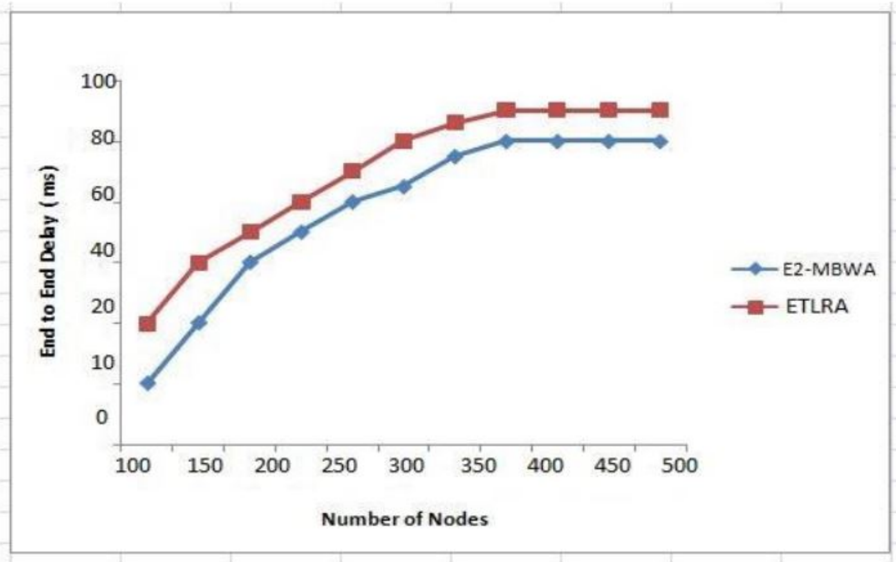

Fig. 6. Comparison of E2-MBWA and ETLRA (End-to-end delay).

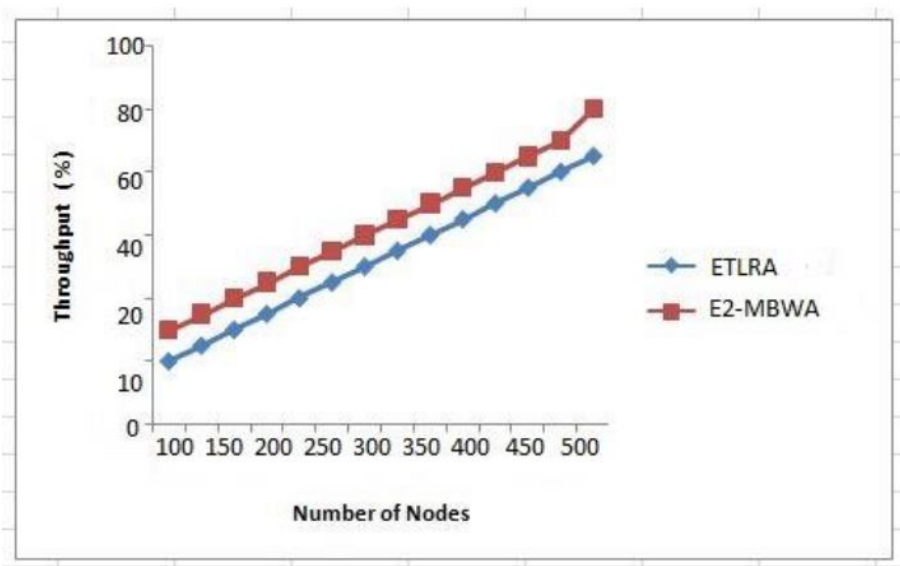

Fig. 7. Comparison of E2-MBWA and ETLRA (Throughput).

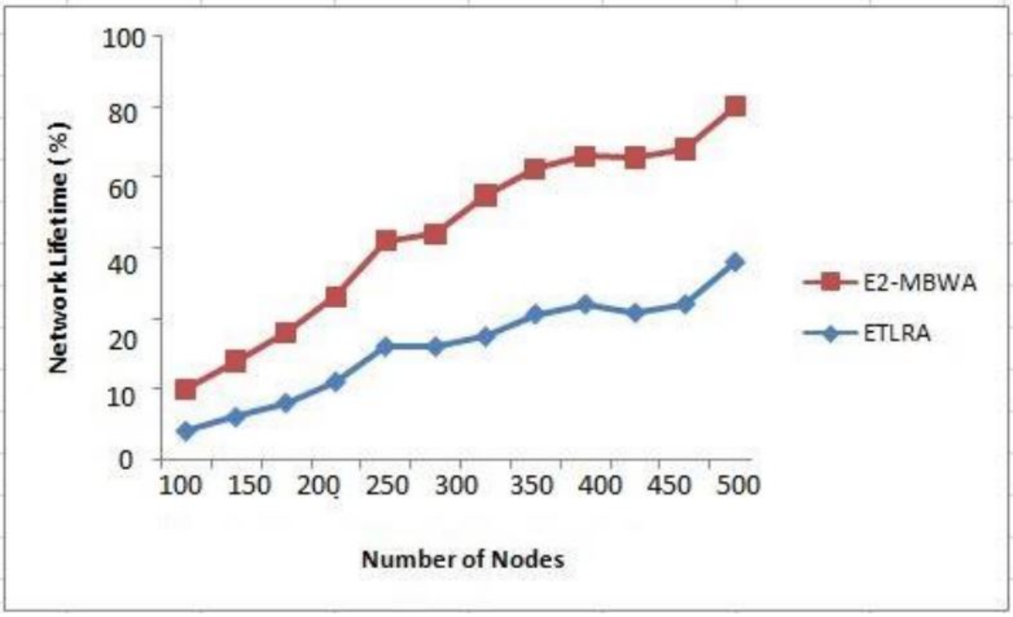

Fig. 8. Comparison of E2-MBWA and ETLRA (Network Lifetime).

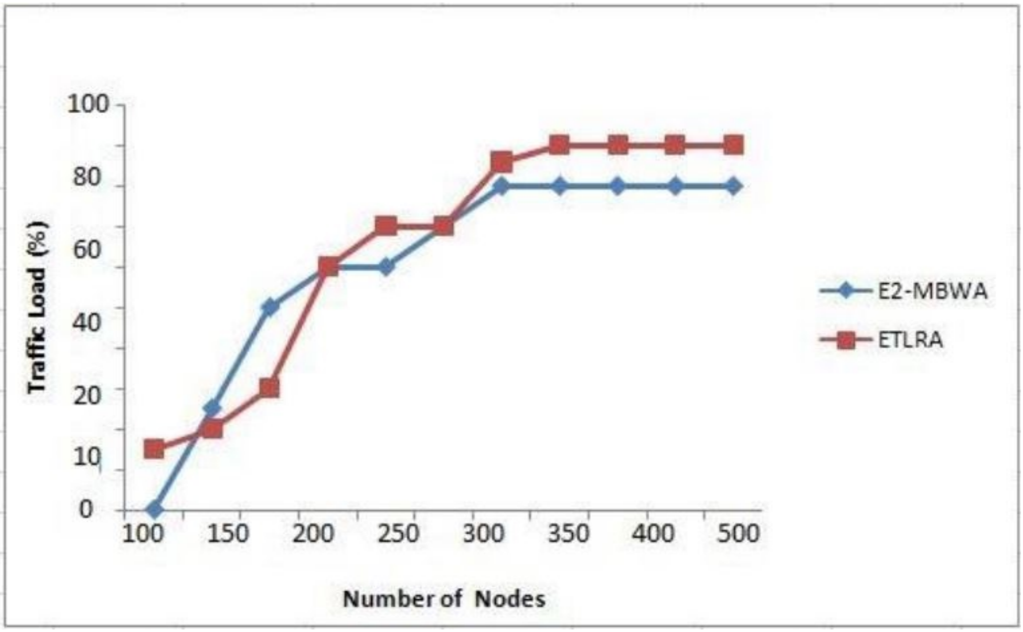

Fig. 9. Comparison of E2-MBWA and ETLRA (Traffic Load).

8. Conclusion

The major aim of this research work is to explore the Hotspot problem and its overall effects on wireless sensors and actor-network. Up to our best knowledge, E2-MBWA is the first algorithm that has deal functionality by mean mobility property/characteristics and energy-efficient for wireless sensor and actor-network, at the same time. The complete algorithm consists of two sub-algorithms like Watchman Node Assigning Algorithm (WNAA), Watchman Secondary Nodes Algorithm (WSNA). The novelty of this algorithm is to work in a dynamic environment, suitable for small or large-scale networks, mobility management between nodes, assigning IDs and maintain the energy status of the network and monitoring of the network by using watchman nodes. The important thing about E2-MBWA the network lifetime does not decrease enough for large-scale networks and improves the PDR of the network. Consequently, it can be said that the proposed algorithm achieves all possible targets discussed in aforementioned section. Furthermore, our future work is to design an intelligence algorithm by using machine learning techniques for wireless sensor networks that auto mitigates such issues in this domain.

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