Energy Efficient Low Latency Routing Design for Target Tracking Applications of Wireless Sensor Network

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Abstract- Target tracking is the greatest important applications in Wireless Sensor Networks (WSNs). The wireless sensor network applications have been increasing since the IoT has been established. Most of the applications have various kind of sensors to transmit the information from one source to another. The basic operation of a wireless sensor network is to sense the data, collect the data and transmit the data from time to time whenever the base station requires the data for evaluation. Improving the reliability, performance for the collection of the data is the main role of the wireless sensor device. Moreover, the objective of the wireless sensor network device is to minimize the latency and improve the energy efficiency in order to provide more reliability is a major performance metric for provisioning WSNs. In this paper, we have presented an Energy Efficient Low Latency Routing (EELLR) design for Target Tracking (TT) Applications of Wireless Sensor Network. This model provides reliability and has a better performance in terms of communication overhead, energy efficiency and packet processing latency reduction when compared with the existing routing-based models.

Keywords: ***Energy Efficiency, Wireless Sensor Network, Routing, Target Tracking, Latency.***

I. INTRODUCTION

Various kind of sensors are being currently used in many fields of development, agriculture, and detection etc. adopting wireless sensor network. The wireless sensor networks have an advantage like they are small in size and can be deployed easily. This advantage of the wireless sensor network helps in the tracking and to locate the moving target in different applications [1]. Hence, many algorithms have been used in different fields like civilian and military fields. Moreover, the wireless sensor networks resolve the issue for many problems and provides a solution for target tracking.

Using the wireless sensor network, the target tracking can be performed easily, but during the tracking many problems arise due to the energy restraint on a given node and the reduction in the accuracy for the target tracking [2]. To resolve this issue many methods have been proposed which increase the accuracy for target tracking and provides an efficient energy to the nodes [3]. In [4], they have proposed a method, Distributed Learning Automaton (DLA), which finds the number of nodes which can provide better Quality-of-Service (QoS) requirements, reduce the consumption of energy by the node and have an overall better performance. Nowadays most of the applications use the prediction tracking based methods which provides with better accuracy and consumes less energy [9]. In [10], they have proposed an algorithm which uses the signal intensity of the wireless sensor node for the selection of the cluster head. The selection of the cluster head is done on the basis of communication range, data fusion and data collection.

The main aim of the routing-based algorithms is to reduce the consumption of energy and increase the lifetime of the system. The study to reduce the consumption of energy in the wireless sensor networks has been going on for several years. As the wireless sensor devices will use the batteries to transmit the data from the wireless sensor network to the base constantly and they usually run for several years and the replacement of the batteries is a big issue [7], [8]. Hence, the main aim of the wireless sensor network is to preserve energy. The energy efficient low latency routing model for machine-to-machine sensor network are classified into hop-based and cluster-based routing model.

In [5], they have presented a model, Low Energy Adaptive Cluster Head (LEACH) which utilizes the routing-based method to improve the energy efficiency of the node. This model showed the advantages of using the cluster-based method instead of the hop-based transmission method. Moreover, as the node size increases, this model fails to provide better results. This proves that the LEACH method does not perform well in large regions because of more cluster heads [6]. In [7], they have proposed a model using the fuzzy-based clustering method which enhances the performance by reducing the energy consumption in the wireless sensor network. Both these models [6] and [7] induce energy overhead among Cluster Head (CH) closer to the gateway node. To resolve these problems [8] a model, (Type-2 Fuzzy Learning) T2FL has been proposed which distributes the workload among different sensors in order to increase the lifetime of the sensor. However, this model didn't provide any prerequisites for the real-time modern wireless network applications. Hence, some of the efficient methodologies are required for real-time modern wireless network applications.

In [13], they proposed a data collection method, [14] proposed a clustering method and [15] proposed a prediction method for the cluster-based network. The model [13]-[15] limited energy dispersal of wireless sensor network hubs; regardless they didn't consider tending to information transmission latency. For limiting the latency [16] implemented evolutionary computing [17] for the formation of the cluster which induced more computational overhead. Due to this problem the wireless sensor device fails and results in loss of connectivity. In [18], they proposed a routing method for the heterogeneous wireless sensor network [21] that transmits the packet to the respective node to the base station with less energy consumption and less packet loss. Moreover, this method did not resolve the problem of data transmission latency. Hence, to reduce energy consumption and data transmission latency, different methods have been proposed [22]-[25]. In [26], they proposed a fuzzy-based cluster selection method and in [27] implemented multipath-based transmission method. Both [26] and [27] accomplished great outcomes when contrasted with the existing data transmission methods. Though, it did not utilize the dynamic varying nature of the climate conditions of the target tracking applications [28], [29]. Hence, this leads to the improper scheduling for the energy consumption and packet loss which overall all affects the target tracking application [30]-[32].

To resolve all the problems that have been discussed above, this work presents an energy efficient low latency routing for target tracking (EELLR-TT) for wireless sensor network. In this model, the wireless sensor devices are deployed in various regions in a fixed network region. Then the position of each of the wireless sensor network device and its side device is obtain using the signal strength. After the position of the wireless senor network is obtained, a method for the selection of cluster head to provide reliability in the connection of the wireless sensor network is proposed which provides a balance in energy efficiency and improves the network coverage in the given fixed network region in order to reduce communication overhead and latency.

II. ENERGY EFFICIENT LOW LATENCY ROUTING DESIGN FOR TARGET TRACKING IN WSNS

In this section, the Energy Efficient Low Latency Routing Design for Target Tracking Applications for the WSNs has been discussed. In [20], the target tracking of the application has been performed using Fuzzy H-Infinity filtering method. In this model, the wireless sensor network devices are implanted with the tracking sensor which is provided with a battery to provide power and also to carry out all the sensing operations that a tracking sensor has to perform. Moreover, the wireless sensor network devices are mostly placed in various locations such that it can sense different regions and transmit the data of each region to the edge device for the further data calculation and evaluation. The whole process is given in Figure 1.

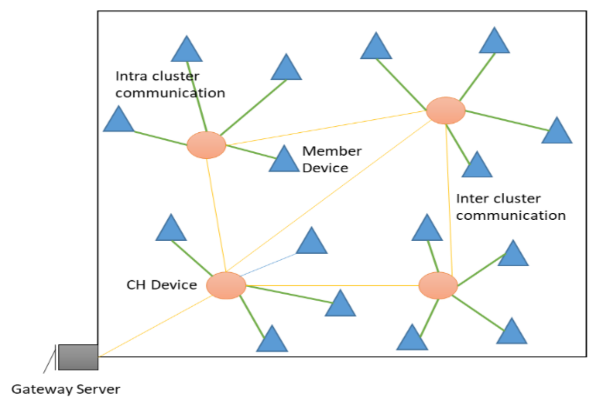

Figure 1. Framework for our proposed model for target tracking in wireless sensor networks.

To improve the efficiency of energy in the wireless sensor networks, this model uses the method of cluster-based-communication. The given method of cluster-based-communication is performed in two steps. The first step is the intra-cluster communication where the wireless sensor network devices will interconnect directly to the given cluster head of the device. In the second step the inter-cluster communication is performed in which the wireless sensor network cluster head will send the packets to the nearest wireless sensor network cluster head directly to the edge broker.

A Selection of cluster head to provide reliability in the connection of the wireless sensor network

In the existing models, the cluster heads of the device were selected on the basis of the threshold parameter. For an instance, the existing system like the LEACH, it utilizes the cluster head by the consideration of the wireless sensor network device having high energy for a given time (rounds). Though, by the utilization of the existing cluster head methods, it is not an efficient way to improve the network coverage and the existing cluster head methods reduce the lifetime of the wireless sensor networks application service. This problem arises because some of the wireless sensor networks are placed in a region where the multiple overlapping devices co-exist and in some of the areas only two or more devices will be overlapping. Hence to resolve this issue and to improve the network lifetime and coverage of the wireless sensor network, this paper presents a model to provide reliability and an improved threshold scheme to select the proper cluster head for target tracking.

In this model, first the distance between the overlapping wireless sensor network devices is computed using the wireless sensor network device distance p which is in the region $0 \leq p \leq 2p$. The distance of the overlapping wireless sensor network is calculated using the following equation

$$O_F = 2p^2 \left[\theta - \frac{p}{2p}\sqrt{1-\left(\frac{p}{2p}\right)^2}\right], \quad (1)$$

In the Equation (1), the θ is evaluated using the given equation

$$\theta = \cos^{-1}(p/2p). \quad (2)$$

The wireless sensor devices which are normally overlapping is attained using the given equation

$$\omega = O_F/\pi p^2 = 2\left[\cos^{-1}(r) - r\sqrt{1-r^2}\right]/\pi, \quad (3)$$

In Equation (3), the value of ω will be in between 0 and 1 which can be described as $0 \leq r \leq 1$. Here the r is used to depict the mean ratio of the WSN device cluster head with respect to the particular time. The evaluation of r is done using the given equation

$$r = p/2p \quad (4)$$

For the improvement of the selection of the cluster head and also to improve the network coverage and lifetime of the wireless sensor network, this model provides a probability value to each of the wireless sensor network devices for being a cluster head. The value of the probability depends on the normal active coverage region with respect to the maximum coverage region of the respective wireless sensor network device. The active coverage region is given using the ratio of the active coverage region with respect to the maximum coverage region of the respective wireless sensor device. Hence, the normal active coverage region for the wireless sensor network device is calculated using the following equation

$$\mu = \mu_0 + \sum_{n=1}^{\infty} \frac{\mu_n}{n+1}. \quad (5)$$

In Equation (5), μ will be in between the range $(0,1)$. If the value of μ is evaluated as 1, then there is no overlapping device for a particular wireless sensor network device. If the value of the μ is evaluated as less than 1 or 0, then there exists a multiple overlapping wireless sensor network device for a given particular wireless sensor network. Moreover, to obtain a normal active coverage region of the wireless sensor network device in a given network which has an efficient energy, the equal distance $\bar{p}$ between the wireless sensor network utilizing the mean signal strength R_p which is received from the adjacent device is established. The whole process of the normal active coverage region is evaluated by transmitting the hello messages to the sender and the receiver. After the whole process is completed, this model takes the value of the normalized overlapping region $\omega(d)$ for the respective wireless sensor network device d using the Equation (1), and $r = \bar{p}/2p$. From Equation (3), the normalized active coverage region is recognized using the given equation

$$\mu(d) = \mu_0 + \frac{\mu_1}{2} = [1 - \omega(d)] + \frac{\omega(d)}{2} = 1 - \frac{\omega(d)}{2}. \quad (6)$$

The attained value from the Equation (6) will provide a less probability to a given wireless sensor network device which is a cluster head for a given network on the basis of higher $\mu(d)$. Similar to this, high probability will be given to the wireless sensor network device which is a cluster head for a given network on the basis of lower $\mu(d)$. Hence, this model modifies the value of parameter r for the given normalized overlapping coverage area using the following equation

$$r(d) = \propto \times\, \omega(d), \quad (7)$$

In Equation (7), the $\propto$ is used to describe the average size of the cluster head. Hence, the improved threshold value $H(d)$ to select a correct cluster head for a given wireless sensor network device d is given using the following equation

$$H(d) \begin{cases} \dfrac{r(d)}{1 - r(d) \times [\varphi mod(1/r(d))]}, & if\ d \in \bar{S}; \\ 0, & Otherwise. \end{cases} \quad (8)$$

In Equation (8), φ is used to denote the current session time (round) and is in the range $0 \leq \varphi < \infty$. $\bar{S}$ is used to denote the value of wireless sensor network device which has not been a cluster head for a long period of time. d is used to denote the cluster head for a current working session $1/r(d)$. Using this method, each of the wireless sensor network device is elected as a cluster head for a given instance of time having different probabilities.

The attained values from the Equation (8) will provide a small $\mu(d)$ to the high probability cluster head for a small amount of time. Similar to this, high $\mu(d)$ will be given to the less probability cluster head with more amount of time. Furthermore, it can be seen that a cluster head having high $\mu(d)$ has an improvement in energy efficiency and a small

$\mu(d)$ induces overhead for being cluster head. Using this method, the selection process for the cluster head through the normalized active coverage region improves the performance in the wireless sensor network. After the cluster heads for a given wireless sensor network has been selected, each of the wireless sensor network device will transmit the data with the respective wireless sensor network cluster head in a given instance of time using TDMA (time using time division medium access).

Let B denote the packet size. To provide a reliable connection between the cluster head and the wireless sensor network and to reduce the failure of transmission of packets, the failure probability $L_{\prime}^{p}$ is given using the equation described below.

$$L_{\prime}^{p} = 1 - (1 - L_{\prime}^{b})^{B}. \quad (9)$$

In Equation (9), the $L_{\prime}^{b}$ denotes the mean bit error rate of both the inter and intra-cluster communication. After the selection of the cluster head and when the probability of the packet failure is obtained, an efficient routing path $L_{\mathcal{M}}$ is established which uses less energy and has less latency using the following equation

$$L_{\mathcal{M}} = \mathcal{E}_{v} + \mathcal{G}_{l} + \overrightarrow{L}_{\prime}^{p} \quad (10)$$

In Equation (10), the $\mathcal{E}_{v}$ denotes the remaining energy of the wireless sensor network device. $\mathcal{G}_{l}$ denotes the anticipated hop size. This provides reliability for the wireless sensor network devices as each of the wireless sensor network can become a cluster head for a given instance of time and can provide a reliable connection between the sender and receiver, hence, this provides a good performance in the target tracking applications. The proposed method also provides an efficient low latency routing method for the target tracking application which reduces the energy and latency dissipation for the transmission of information in packets in the wireless sensor network.

III. Results and Discussions

In this section the attained results for the experimentation have been discussed. The experimentation has been performed on the system having an Intel quad processor. The system consisted of the 8 GB of RAM and we have used the SENSORIA simulator [19] to test all the results of our model EELLR-TT using the Windows 10 operating system. For the comparison of the results with the existing system we have used the LEACH-based routing existing method [26], [27] to compare the results with our EELLR-TT model. This method has been coded in the C++ and C# programming language. All the parameters that have been used in the LEACH-based routing method have been taken into consideration to compare with our proposed EELLR-TT model. The target tracking application using Fuzzy H-infinity filter [33] is used for studying performance of different models. The target trajectory dataset is taken from [36]. The parameters have been described using the Table 1 and all the values of each parameter have been given in Table 1 which is given below.

Table 1. Parameters considered for the analysis of performance and reliability for both the proposed model EELLR-TT and the existing model LEACH

Parameter	Value
Simulation area	$50 meters \times 50 meters$
Base stations	1
Number of devices	$300\ to\ 1800$
Transmission range	$15\ meters$
Sensing range	$10\ meters$
Initial energy	$0.01 - 0.2\ Joules$
Radio energy consumption	$50\ nj/bit$
Control packets length	$512\ bits$
Data packets length	$1000\ bits$
Data transmission speed	$100\ bit/sec$
Bandwidth	$10000\ bit/sec$
Idle phase energy consumption ($Eelec$)	$50\ nj/bit$
Signal amplification energy (Emp)	$100\ pJ/bit/m2$

A. Network Lifetime Performance

In this section, the experimentation has been performed to evaluate the performance of the network lifetime of the node. Both the existing model LEACH and proposed model EELLR-TT have been evaluated for the network lifetime performance by the consideration of the overall death nodes. For the evaluation of the performance of the network lifetime, a fixed network region has been considered in which the wireless sensor network devices have been scattered in all the regions in the fixed network region. The results of the performance have been shown graphically using the Figure 2.

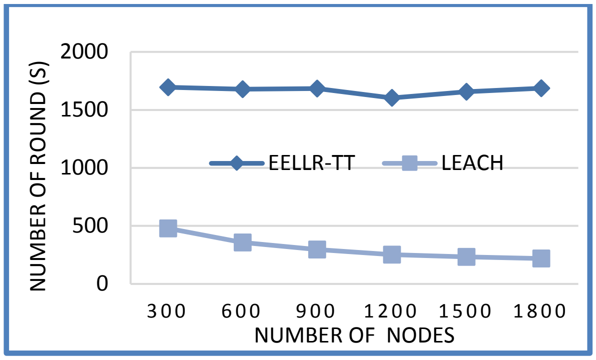

Figure 2. Lifetime of the network varied with the size of the node (Overall death node)

From the Figure 2 it can be seen that there is an improvement in our EELLR-TT model when compared with the existing LEACH-based routing model. The nodes considered for the experimentation have been considered as 300, 600, 900, 1200, 1500 and 1800 nodes which show an improvement of 71.74%, 78.77%, 82.43, 84.22%, 85.98%, and 87.02% respectively for our EELLR-TT model when compared with the LEACH model.
Furthermore, the evaluation of the performance of the network lifetime has been evaluated by considering the loss of connectivity in the network. For the evaluation of the performance of the network lifetime by the consideration of the loss of connectivity, a fixed network region has been considered in which the wireless sensor network devices have been scattered in all the regions in the fixed network region. The performance of the loss of connectivity in the network lifetime has been shown graphically using the Figure 3.

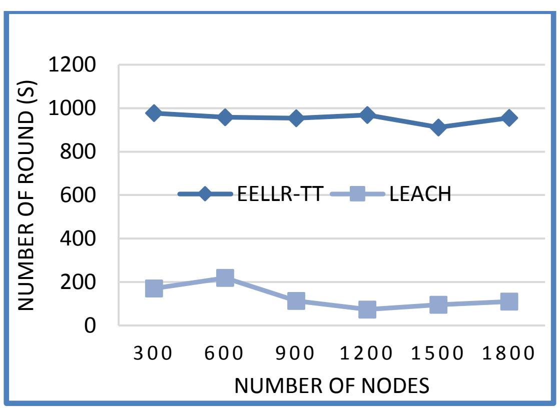

Figure 3. Lifetime of the network varied with the size of the node (Overall death node).

From the Figure 3 it can be seen that our EELLR-TT model has a better performance in the loss of connectivity when compared with the existing LEACH-based routing model. The nodes considered for the experimentation have been considered as 300, 600, 900, 1200, 1500 and 1800 nodes which show an improvement of 82.497%, 77.16%, 88.05%, 92.36%, 89.58%, and 88.39% respectively for our EELLR-TT model when compared with the LEACH model.

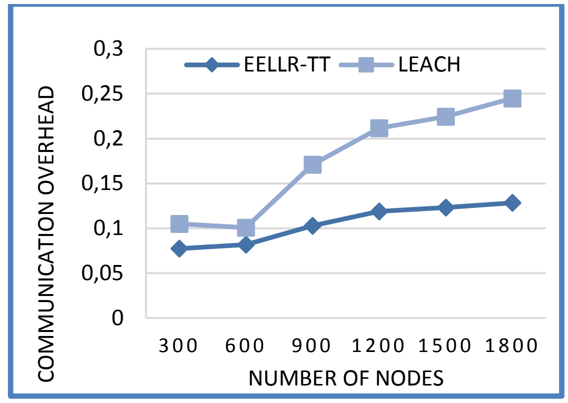

Figure 4. Network Communication Overhead varied with the node size.

B. Communication Overhead Performance

In this section, the experimentation has been performed to evaluate the performance of the network communication overhead. Both the existing model LEACH and proposed model EELLR-TT have been evaluated for the network communication overhead by the consideration of the nodes. For the evaluation of the performance of the network communication overhead performance, a fixed network region has been considered in which the wireless sensor network devices have been scattered in all the regions in the fixed network region. The results of the performance have been shown graphically using the Figure 3.
From the Figure 4 it can be seen that there is an improvement in the network communication overhead in our EELLR-TT model when compared with the existing LEACH-based routing model. The nodes considered for the experimentation have been considered as 300, 600, 900, 1200, 1500 and 1800 nodes which show an overhead reduction of 26.33%, 18.93%, 39.78%, 43.85%, 45.03%, and 47.59% respectively for our EELLR-TT model when compared with the LEACH model. Our model reduces the overall network communication overhead by 36.92% when compared with the existing LEACH-based routing model. From the Figure 4 it can be noticed that as the number of nodes increase the wireless sensor device density also increases in both the proposed and existing models.

C. Data Processing Latency Performance

In this section, the experimentation has been performed to evaluate the performance of the data processing latency overhead. Both the existing model LEACH and proposed model EELLR-TT have been evaluated for the network communication overhead by the consideration of the nodes. For the evaluation of the performance of the data latency overhead performance, a fixed network region has been considered in which the wireless sensor network devices have been scattered in all the regions in the fixed network region. The results of the performance have been shown graphically using the Figure 5.

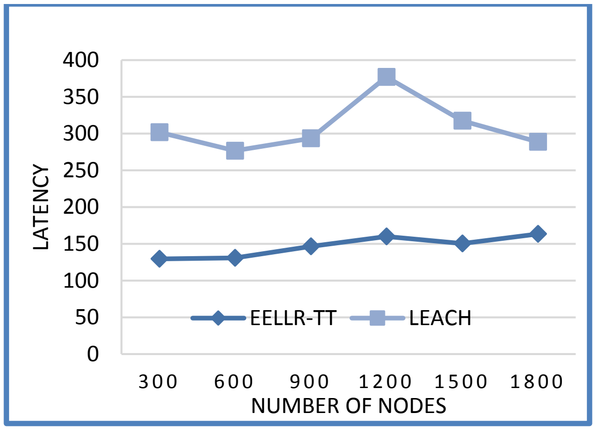

Figure 5. Data Latency Overhead varied with node size.

From the Figure 5 it can be seen that our EELLR-TT model has reduced the data latency overhead when compared with the existing LEACH-based routing model. The nodes considered for the experimentation have been considered as 300, 600, 900, 1200, 1500 and 1800 nodes which show a reduction of 57.1%, 52.7%, 50.03%, 57.61%, 52.6%, and 43.38% respectively for our EELLR-TT model when compared with the LEACH model. Our model reduces the overall network data latency overhead by 52.23% when compared with the existing LEACH-based routing model.

D. Routing Overhead Performance

In this section, the experimentation has been performed to evaluate the performance of on the network routing overhead. Both the existing model LEACH and proposed model EELLR-TT have been evaluated for the network routing overhead by the consideration of the nodes. For the evaluation of the performance of the data latency overhead performance, a fixed network region has been considered in which the wireless sensor network devices have been scattered in all the regions in the fixed network region. The results of the performance have been shown graphically using the Figure 6.

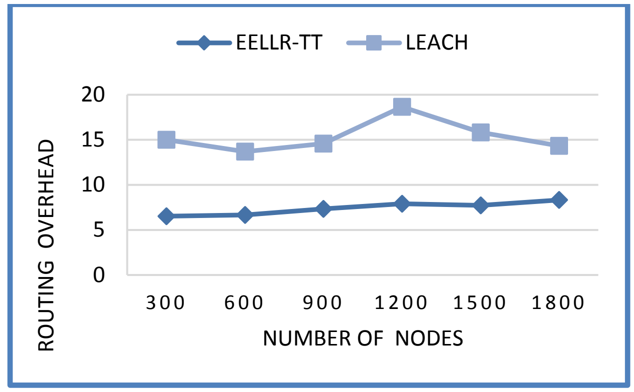

Figure 6. Network Routing Overhead varied with node size.

From the Figure 6 it can be seen that our EELLR-TT model has reduced the network routing overhead when compared with the existing LEACH-based routing model. The nodes considered for the experimentation have been considered as 300, 600, 900, 1200, 1500 and 1800 nodes which show a reduction of 56.48%, 51.45%, 49.69%, 57.69%, 51.19%, and 41.94% respectively for our EELLR-TT model when compared with the LEACH model. Our model reduces the overall network routing overhead by 51.40% when compared with the existing LEACH-based routing model.

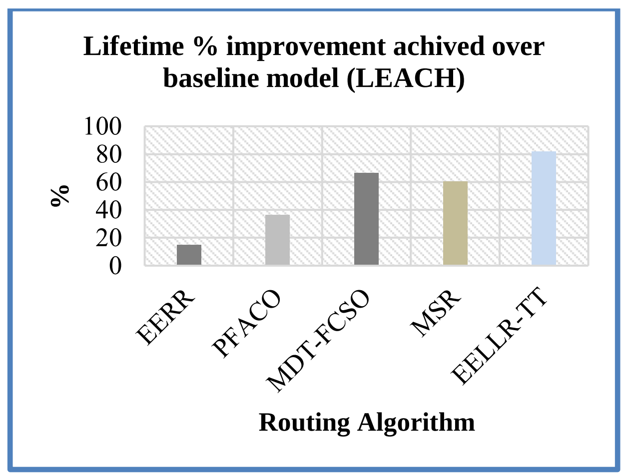

Figure 7. Comparison of existing models and proposed EELLR-TT model with respect to the network lifetime performance under overall wireless sensor network device death.

E. Comparative analysis of EELLR-TT over state-of-art routing methods for wireless sensor networks

In this section, the proposed EELLR-TT method has been compared using the existing routing-based methods which have been used for target tracking applications. The Figure 6 describes all the results compared with the existing methods. From the Figure 7 it can be seen that our model has a better performance and provides more reliability when compared with the other existing models such as energy efficient reliable routing (EERR) [20], PFuzzyACO-based routing model [26], Multipath data transmission model using Fuzzy cat swarm (MDT-PFCSO) [27], and multi-sink routing (MSR) [35]. The Table 2 also shows comparative table of different methods. The table 2 shows existing method uses fuzzy rule and cat swarm optimization; thus, suffers from for non-polynomial deterministic optimization problem. However, the EELLR provide optimization through simple minimization function in solving multi-objective function. Further, none of the existing routing method minimize latency. However, the EELLR are very food in minimizing latency and energy consumption.

Table 2. Comparative Study

	Multi-objective	**QoS support**	**Optimization**
EERR	No	No	Yes
PFACO	Yes	No	Fuzzy rules
MDT-FCSO	Yes	Yes	Fuzzy and swarm
MSR	Yes	No	Linear optimization
EELLR-TT	**Yes**	**Yes**	**Minimization function**

IV. CONCLUSION

This paper provides an Energy Efficient Low Latency Routing Design model for Target Tracking Applications for the wireless sensor network which provides a reliable routing method which reduces the energy and provides a reliable mode of connection for target tracking applications. The most difficult task in a wireless sensor network device is to reduce the consumption of energy. The upcoming future application require less consumption of energy, less latency and more reliability. Most of the existing models have faced an issue to reduce the energy and provide reliability for the connection between the cluster head and the wireless sensor network both at the same time. Many existing methods utilize the swarm optimization method or fuzzy method for the transmission of the information. These models have failed to provide the reliability in the wireless sensor networks during the transmission of data, hence this model has been developed. The model shows better results to provide a reliable connection for the target tracking applications when compared with the existing system, LEACH, which uses the cluster-based routing method rather than the hop-based transmission method. For the future development the routing performance of the target tracking application can be evaluated using other filters.

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