A Metaheuristic Approach Towards Enhancement of Network Lifetime in Wireless Sensor Networks

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Abstract

Sensor networks are now an essential aspect of wireless communication, especially with the introduction of new gadgets and protocols. Their ability to be deployed anywhere, especially where human presence is undesirable, makes them perfect choices for remote observation and control. Despite their vast range of applications from home to hostile territory monitoring, limited battery power remains a limiting factor in their efficacy. To analyze and transmit data, it requires intelligent use of available battery power. Several studies have established effective routing algorithms based on clustering. However, choosing optimal cluster heads and similarity measures for clustering significantly increases computing time and cost. This work proposes and implements a simple two-phase technique of route creation and maintenance to ensure route reliability by employing nature-inspired ant colony optimization followed by the fuzzy decision engine (FDE). Benchmark methods such as PSO, ACO and GWO are compared with the proposed HRCM's performance. The objective has been focused towards establishing the superiority of proposed work amongst existing optimization methods in a standalone configuration. An average of 15% improvement in energy consumption followed by 12% improvement in latency reduction is observed in proposed hybrid model over standalone optimization methods.

Keywords: Wireless sensor networks, Network Lifetime, Quality of Service, Routing, Meta-heuristics, Throughput.

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1. Introduction

Rapid advances in information processing and communication technology have given rise to a plethora of applications targeted at reducing and maximizing consumer sophistication on a global scale. Wireless sensor networks (WSN) are a hot new research and development issue. These nodes are the backbone of any WSN design and have limited computing/processing capabilities because of the limited power provided by batteries. WSNs have the advantage of being able to be deployed in remote areas where human presence is not possible or feasible. These include natural disasters such as volcanoes, earthquakes, floods, and hostile territory along international borders. A typical scenario of WSN implementation is projected in section I as shown below.

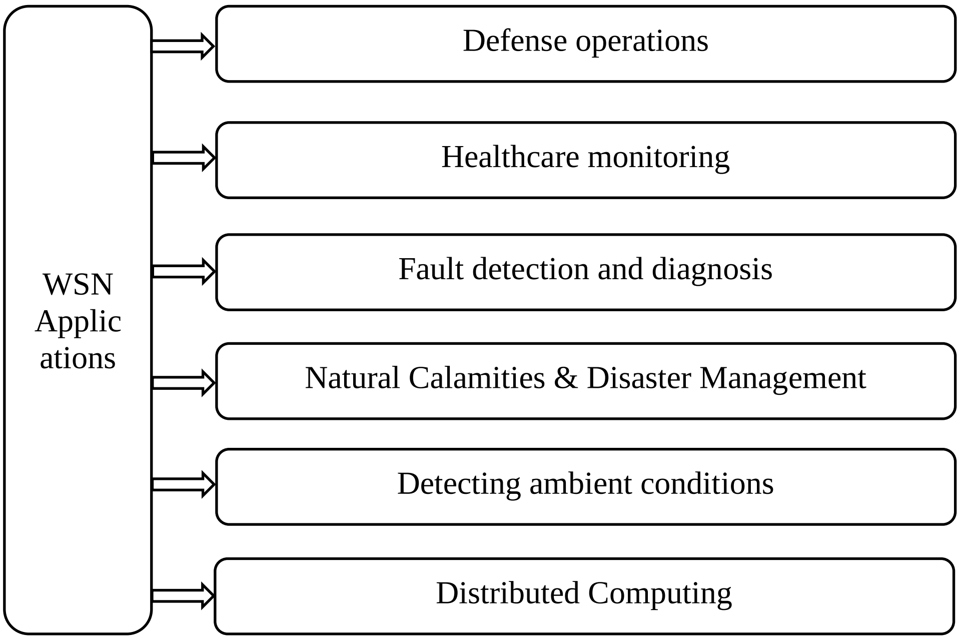

Fig. 1. Illustration of typical WSN applications

As shown in **Fig. 1**, WSN applications include WBANs, MANETs, VANETs, and V2V communication in vehicles. Regardless of the application, WSNs typically operate by transferring data from one point to another. To perceive the surroundings and convey them to the destination, the source is typically formed of sensing nodes or terminal nodes installed at the scene of interest (SoI) [1]. Routing is a critical step in creating a communication path. Its performance features include throughput, end-to-end delay, and energy consumption. These aspects contribute to the overall performance of the WSN, often known as Quality of service (QoS) [2]. Among the essential and critical parameters, the routing algorithm's reliability and latency are extremely important [3]. Reliability is a complex attribute that depends on the node's residual energy, trustworthiness, and processing ability [4].

The second criterion, known as latency, describes the rate at which a data packet is transferred across a network of nodes from its source to its destination. This necessitates the routing algorithm to select the ideal shortest path with the least amount of expense. Another important point to make is that latency and reliability go together. Packets have to wait for an alternate path to be selected by the routing centre when the node fails during a communication process [5] - [6]. Load balancing is another key feature seen where, in the case of dynamic traffic situations, pathways may suffer low traffic rates because certain active nodes not involved in the communication process may utilize power, resulting in increased energy consumption. However, nodes with low average energy may face higher delays or packet loss to accommodate existing communication channels or routes. Both situations are undesirable and reduce QoS significantly. In order to improve the total network lifetime, considerable study has been done in the literature on intelligent energy management by nodes [7] - [8]. Distance of nodes from base station, node density, inbound traffic density, energy of nodes are all key aspects impacting routing algorithm creation [9].

This paper's major objective is to discuss network reliability and latency, based on preliminary findings. Specifically, this study suggests a route development and maintenance approach, which is implemented in two stages. For route creation, an ant colony optimization (ACO)-based optimization technique is proposed, while for route maintenance, a fuzzy-based trustworthy computation approach is used. This research paper proposes and tests these two algorithms, which are together known as F-ACO, or fuzzy ACO. The suggested route design and maintenance phase use dynamic traffic scenarios and distance as fundamental criteria, whereas the proposed route maintenance phase uses a continuous and iteration-based trustworthy computation and update mechanism. In existing works, stand-alone or hybrid algorithms have been used to address both route discovery and maintenance which does not strike a perfect trade-off between the two phases. The algorithm either tries to obtain optimality either on one of the phases, route discovery or route maintenance, but at the cost of the other's efficiency, thus resulting in reduction in overall efficiency. However, in this proposed work, dedicated algorithms or models have been deployed to handle route discovery and route maintenance without any additional overhead, which is the novelty of this proposed approach.

Beforehand, the paper is formulated systematically into sections. Section 2 gives an insight into energy efficient and latency aware routing methodologies from recent literature while section 3 provides the problem formulation and the proposed solution through a two-phase strategy. Section 4 provides an extensive analysis into the experimentation for various scenarios while section 5 draws the concluding remarks based on the experimental findings.

2. Related Work

Several research works are observed in the literature with respect to network life improvement of WSNs. Various routing protocols have evolved over the past decade to improve wireless sensor network performance. Several recent studies have come up with ways to improve the overall performance of WSNs. These include relay node selection [10], reliability-oriented routing [11], energy-aware, and QoS-aware routing protocols [12]. Clustering-based routing gains more attention among others. Various clustering-based routing protocols are reported in [13] - [14] including the familiar Adaptive threshold sensitive energy-efficient sensor network (APTEEN), Low energy adaptive clustering hierarchy (LEACH), and Power-efficient gathering in sensor information systems (PEGASIS) Virtual grid architecture routing (VGA) protocols. Among all, LEACH gains more attention due to its unique features. Leach is a hierarchical routing protocol that improves the network lifetime through its clustering properties [15]. Different types of LEACH protocols are analyzed in [16] - [17] based on energy efficiency, scalability, communication overhead, etc., Identifying cluster heads based on the lowest distance from the base station to reduce energy consumption is the major merit of the LEACH protocol [18]. This power consumption minimization enhances the network lifetime. Recently, LEACH has been combined with machine learning and optimization techniques as a hybrid model to attain better performance [19]. In [20], a genetic algorithm is combined with LEACH as LEACH-GA to improve the network lifetime by modifying the cluster probability and residual energy levels.

AODV is an age old and well – known routing methodology [21] belonging to a specific class of routing methods namely the reactive routing methods. They are based on the 'on-demand' basis as their name indicates and use distance vectors to adjacent nodes as the prime method of establishing the routing path from one to another. Distance and the cost incurred in utilizing that path is kept as the parameters for decision making in choice of next adjacent node. However, these methods increase latency in communication due to excessive flooding of broadcast packets to determine active nodes. Clustering based routing protocols have been gaining widespread significance in recent times due to their ability to handle large number of nodes over a wide geographical area. The well-known LEACH (Low energy adaptive clustered hierarchical) protocol forms the backbone of cluster-based topologies. They aim in selecting a single and able node amongst a group of nodes to perform and coordinate all the communication processes. This single node, termed as the cluster head (CH), is selected on various criteria thus resulting in different variants of the clustering process.

LEACH and cluster-based protocols work on the simple phenomena or principle of energy consumption reduction by replacing the functionalities of various nodes in the WSN with the single cluster head selected node. This causes the nodes which are not taking part in the communication process or left out of the cluster to switch off to IDLE state thus saving power. One method of cluster head selection in LEACH is observed to be based on the distance of the CH from base station [Salem] to reduce the power consumption of the cluster head node itself. This is found to account for considerable improvement in network lifetime. A regional LEACH protocol is investigated in the literature [22] where the entire geographical region is divided into rectangular regions and independent and individual LEACH clustering methodology applied. However, an increased computational complexity has been observed in this case. An attempt to stabilize the cluster head count in the conventional LEACH methods has been investigated in the literature [23]. Another method investigated in the literature aims to balance the energy consumption in the conventional LEACH methods [Salim]

Multi-objective LEACH based methods have also been addressed in the literature [24] – [25] where load balancing and energy efficiency are taken as objectives. These methods are quite necessary as a tradeoff exists in the amount of load on the CH which tends to dictate its lifetime. Apart from load balancing, security of data being transmitted across the communication network has also been taken into consideration in the literature [26] in addition to energy efficiency. The information packets have been translated into secret shares as in cryptographic systems using a three phase SEDR algorithm. In this method, the shares or the information packets are distributed throughout multiple paths formulated by the routing methodology and collected at the sink thus ensuring a non-sequential and cryptic form of communication across the system. A cluster-based methodology [27] has been proposed in the literature which is based on location and multi-hop information to select the cluster head which effectively broadcasts the information to other cluster heads and subsequently to the sink. A balanced and prolonged network lifetime are the findings of this research work.

A two-phase methodology has been adopted in cluster-based approach [28], where conventional methods of clustering and cluster head selection is made following which the information is broadcast to all other CHs based on a fuzzy rule base. The routing path is determined using shortest path strategy implemented via Dijkstra algorithm. A balanced and prolonged network lifetime are the findings of this research work. Reduced energy consumption against total capital energy is yet another finding of this experimentation. A load balanced routing method [29] proposed in the literature follows the conventional route formation process with novelty of balancing the node as well as energy consumption by working on the node radios to be in the OFF state for a specific period to reduce power consumption. A service-based approach of routing is proposed in the literature [30] where the user views and their evaluation assessments are used as feedback inputs to a fuzzy engine to reach the optimal convergence point. This work is mainly focused on improving the QoS through user QoS and context QoS inputs. A smart routing methodology [31] has been implemented in the literature where the routing mechanism chooses cluster heads which adapt to changing bandwidth conditions depending on the number of users which are found to dynamically vary from time to time. K-means clustering methodology has been utilized which also helps in identify the peak bandwidth needs. A grid-based technique is proposed in the literature [32] to effectively address the load balancing problem. The grid level-based routing method distributes the load to a group of sensor nodes which are idle or inactive states to reduce the waiting time and thereby effectively reduce the energy consumption.

Whilst many routing methods have focused on reducing the energy consumption and improving the network lifetime, few methods [33] have focused on detection of malicious packets of information which tend to mitigate as authentic users and drawing excess power from batteries thus causing their drain out. Thus, detection of malware also is an important factor in routing algorithm formulations aimed towards improving network lifetime. Nature inspired algorithms or meta-heuristic algorithms have been gaining widespread significance in recent times as they closely mimic the real time scenario which is a daring necessity in visualizing most of the WSN related problems. Optimality is a major factor in most of these meta-heuristics which closely relates with the optimal path finding problem in wireless sensor networks.

As observed from the exhaustive survey of literature, a vast majority of algorithms are focused on clustering which aid in reducing the energy consumption by utilizing concepts of cluster heads which represent a bulk of cluster members. However, the overhead on the cluster head tends to increase under a dynamically varying load conditions and bandwidth conditions which has been taken as the primary objective of research in this paper.

3. Proposed Work

In this paper, a novel two stage routing methodology is proposed based on a non-clustering methodology to improve the overall QoS by addressing reliability and latency as the two primary issues. Two phases are involved namely the Route creation and Route Maintenance. The working methodology is elaborated in this section in a categorical manner.

3.1 Route Creation

The first and foremost step in routing methodology is to establish the route from source to destination given the traffic consisting of information packets. The objective is to establish an optimal route from source to destination. Given a network equated to a graph model $G(V, E)$ consisting of P nodes as shown in **Fig. 2** shown below.

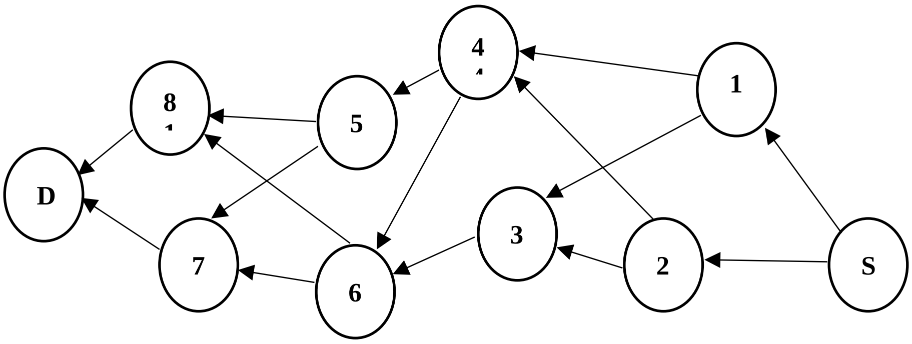

Fig. 2. Illustration of a typical graph connected WSN.

The following requirements are formulated in phase I

a. The nodes in the route created should be trustworthy and reliable.
b. The transmission cost should be optimal minimum which is equated in terms of energy consumed in the communication process.
c. The latency t should be optimal minimum.

Based on the observations of conditions a – c, a nature inspired algorithm which best mimics the above requirements are selected for the proposed route creation process. Ant colony optimization algorithm which is based on the food foraging behavior of ants proves to be an ideal candidate to meet the above criteria. A conceptual illustration of food foraging behavior of ACO is depicted in **Fig. 3** shown below.

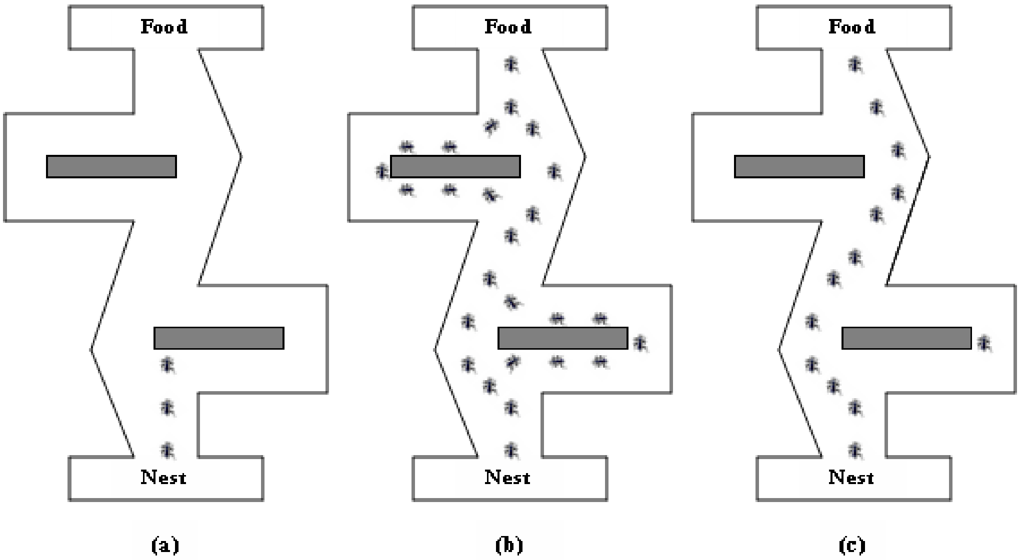

Fig. 3. Illustration of Ant Colony Food Foraging behavior.
(Courtesy: Swarm Intelligence, 2011)

The concept of ACO is based on the real time food foraging behavior of ants which select the optimal route leading towards the food source through a series of iterations through a group of ants which traverse through several paths in the initial stages. An important factor, namely the pheromone secretion by ants, mark the path traversed by the ants. On observing several alternates to the same location of food source, the ACO converges onto an optimal path which has the highest amount of pheromone secretion, which directly reflects the fact that, this optimal path has been travelled often by most of the initial population of the ants and is designated as the optimal path of transportation. This concept is analogously taken for the formulation of establishing an optimal path from source to destination on **Fig. 2** to determine the best optimal path. The proposed method does not involve any clustering methodology and thereby reduces the computational complexity involving selection of clusters, cluster heads and certain rotation policies as observed in the literature. The pseudo code of the proposed ACO based path creation phase is summarized below.

Pseudocode for Ant colony optimization-based path creation

```
Input: G (V, E) //Set of vertices and edges for the given WSN
Output: O(Path_optimal)
Initialize population of ants, pheromone, iterations
        Generate Initial pheromone matrix based on the generated graph
                Initialize ants randomly on the graph vertices
                    Set the amount of food collected into zero for each ant
            For each ant
                   Move forward the ant on the graph based on the probabilistic value
                       Compute the collected food based on the ant pheromone trail
                             Select the ant with largest amount of food and select as optimal
trail
                  Evaluate the pheromone level
          Redirect all the ants to the selected optimal path
     Repeat until all the ants directed towards optimal path
End
```

As depicted in the pseudocode, the initial set of ant population corresponding to the possible set of nodes from source to destination are initialized. The food source in the conventional ACO is analogously taken as the sink or destination in the WSN network. The initial phase progresses by transmission of 'HELLO' broadcast packet using a random path to check the validity and reliability of the path. During this process, each node broadcasts its energy level, distance from BS to the routing control center to assess continuity of existing route or to search for another route. This is easily done by implementation of the ACO process where the level of pheromone is continually monitored to determine the validity and reliability of existing path. It is to be noted that pheromone is evaporative in nature and less secretion causes subsequent convergence of pheromone to zero. This indicates that ants have not utilized the path or have neglected the path due to non-optimality of increasing cost function. Hence, paths characterized by higher pheromone concentration are taken to be the best optimal path from source to destination. If *G (V, E)* analogously reflect the WSN network, the route creation operates as

$Input: G(V, E) \in R = 1,2,3, \ldots\ldots N$
$Output: O(path_{opt}) \leq R = 1,2,3, \ldots N$
$while\ N! = 0$
$\{$
$call\ route\_create\ (\ );$
$\}$
$*\ Route\ Create\ *$
$initialize\ N\ (set\ of\ nodes), P\ (set\ of\ possible\ paths\ where\ P \leq N - 1), i\ (iteration\ index), \nabla\ (pheromone\ deposition), M_{E_r}(residual\ energy, M_{d_{bs}}, M_{tr_{density}};$
$begin$
$\{$
$for\ i = 1;$
$broadcast_{t=initial}'HELLO';$
$compute\ M_{E_r}, M_{d_{bs}}, M_{tr_{density}} for\ all\ N \in R$
$for\ any\ m, n \in G(V, E);$
$compute\ \delta = (1 - \gamma) + \nabla; (\delta = pheromone\ update\ parameter, \gamma = evaporation\ rate)$
$if\ \delta\ (m, n) \geq \delta\ (m - 1, n - 1)$
$then\ path_{opt} \leftarrow \delta\ (m, n)$
$else$
$path_{opt} \leftarrow \delta\ (m - 1, n - 1); i = 1 + 1;$
$\}while\ (i \leq N - 1)$

The above algorithm computes the best path at time $t_{initial}$ based on transmission of initial HELLO packet followed by the information packets after the best optimal path is computed. This process is quite sufficient for traffic of known load patterns which do not exhibit any dynamic change in their behavior. However, in cases of continued change of patterns, the above method is not sufficient for optimal provision of QoS. Hence, a route maintenance method is proposed and implemented to keep a constant check on the network configuration parameters and make them adaptive to the dynamic traffic pattern. A route maintenance pattern involving a fuzzy decision engine (FDE) is implemented which is discussion in the following sub-section

3.2 Route Maintenance

Route maintenance is an essential part in the routing mechanism of WSNs and plays a critical role especially in circumstances where the incoming traffic varies which poses a significant overhead on the nodes resulting in rapid drain of battery power. This results in a quick die out of node lifetime causing a reduction in the overall network lifetime reduction. Route maintenance also helps to maintain and ensure that the links in the current formulated route are health and do not incur any link failure. Since, the route creation is optimal based on a meta-heuristic algorithm, care has been taken not to further increase the complexity and hence, a simple yet efficient fuzzy decision engine has been proposed and implemented to check the validity and reliability of the nodes in the communication process. The flow process of the proposed fuzzy based route maintenance (FRM) is depicted in **Fig. 4** shown below.

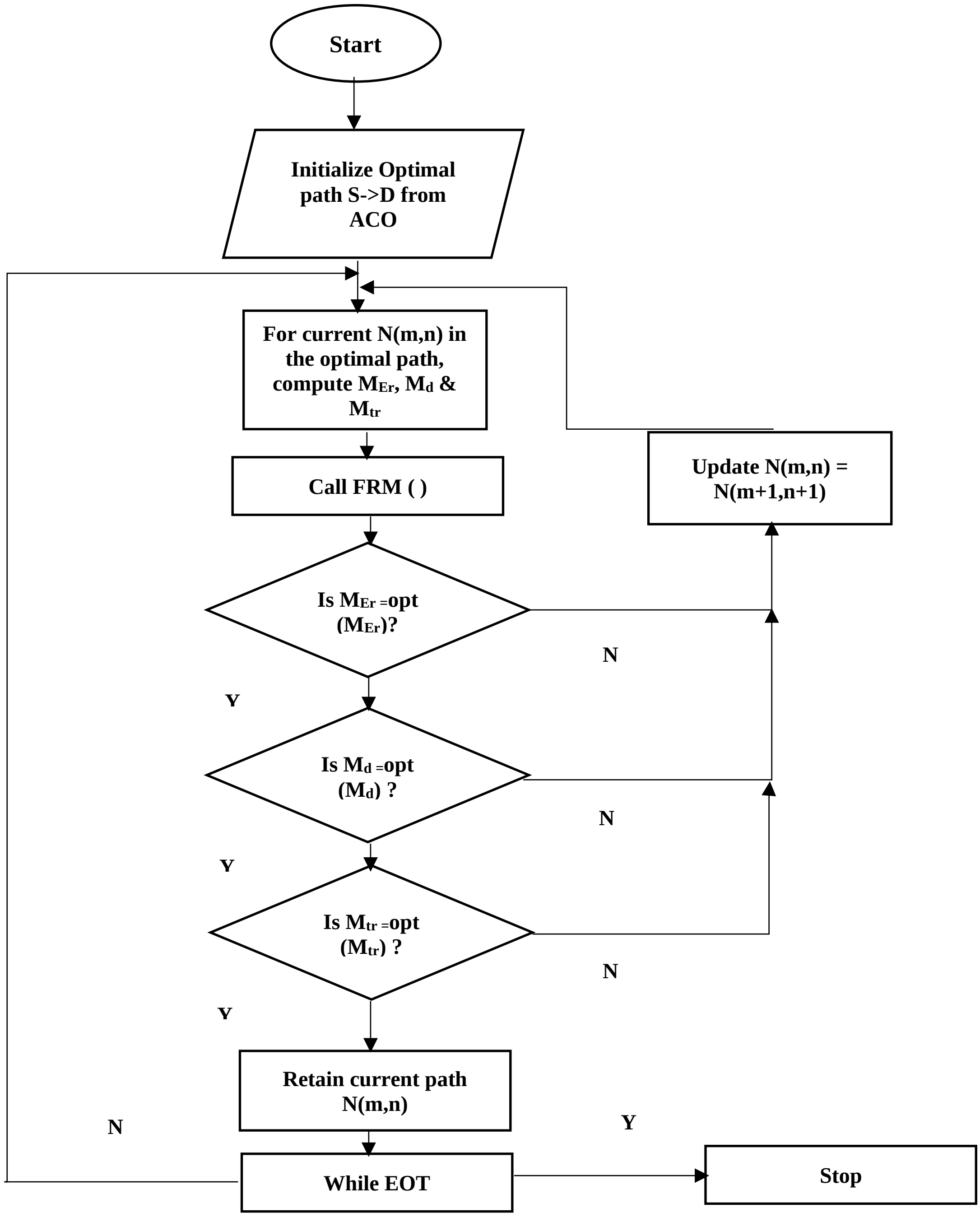

Fig. 4. Illustration of Proposed FRM

Fig. 4 clearly projects the flow process of proposed fuzzy based route maintenance algorithm. A three metric quantity has been formulated to decide upon the trust worthiness of the node/link at any point of time, namely, the residual energy level at the time of communication, distance of that node to the base station and the incoming traffic density to that node.

Once the path has been created by the ACO route creation module, the communication of information through packets commences. At each transmission of information packet from one forwarding node to the next adjacent node in the optimal routing path, the node involved at that point of time communicates its residual energy after having transmitted the current packet of information, its distance to the base station and information related to the traffic of the next incoming packet of information to the FDE. As observed in **Fig. 4**, only when all the three criteria are satisfied, the fuzzy engine decides on retaining the current node for the next packet transmission of information. If any one of the criteria fails, the node is switched over to IDLE state and next adjacent node is check for its parameters. At any point of time, if two adjacent nodes fail in the FDE, the ACO route create algorithm is invoked to create an alternate path. The proposed method is straight forward and does not include any computation complexity. It ensures adequate residual energy in each of the nodes. Vast experimentation has been conducted to test the validity of the proposed method which have been summarized in section 4.

4. Results and Discussion

4.1 Performance Metrics

Keeping in mind the proposed objective of improving the network lifetime, key performance metrics have been identified and recorded for evaluation of proposed model. They include throughput, energy consumption, latency and packet drop ratio (PDR).
The throughput is computed as

$$Througput = \sum_{i=1}^{n} R_d \in N_{lifespan} \tag{1}$$

Where
R_d denotes the received data at terminal node and $N_{lifespan}$ denotes the total lifespan of the network.

The latency is a direct reflection of the throughput. Lower the latency or the end-end delay, higher the throughput and vice-versa. Packet drop analysis is yet another direct reflection of end-end delay analysis and throughput. Higher the packet loss over a period of time, lower the throughput and vice versa.
Energy consumption computation is yet another critical metric to depict the network lifetime which is based on the delay model represented as follows

The delay model is depicted as

$$D(y) = \frac{1}{C_x}\sum_{y-1}^{C_y} dis(N_y, H_x) \tag{2}$$

$$S(y) = \frac{1}{C_x} dis(H_x, B) \tag{3}$$

The total energy consumption of each node in the network for transmit and receive the n bit data packet is given in (4).

$$Total\ Energy = E_{Tr(n,d)} + E_r(n) \tag{4}$$

Where $E_{Tr(n,d)}$ and $E_r(n)$ are energy consumption of transmitting and receiving node.

$$E_t(n,d)=\begin{cases} n\times E_{elec}+n\times\varepsilon_{fs}\times D^2;\ if\ D<D_0 \\ n\times E_{elec}+n\times\varepsilon_{mp}\times D^4;\ if\ D\geq D_0 \end{cases} \tag{5}$$

$$E_r(n)=n\times E_{elec} \tag{6}$$

Where E_{elec} the energy is dissipated per bit to run the transmitter or receiver circuit, amplification energy for free space model (ε_{fs}) and for multi-path model (ε_{mp}) depends on the transmitter amplifier model and D_0 is the threshold transmission distance.

4.2 Performance Metrics

A simple WSN network has been formulated and tested in network simulator 2 environment which is an open-source platform. The simulations settings used for the experimentation have been tabulated in **Table 1** shown below.

Table 1. Simulation settings for proposed HRCMA

Parameters	Values
Topology	1000m x 1000m
Type	Flat
Channel Type	Wireless
No. of nodes	100
Radio propagation model	Two ray ground
Network interface type	Physical/Wireless Model
MAC type	IEEE 802.11
Antenna Model	Omni
Tx power	1.0W
Rx power	1.0W
Initial Energy	10J
Routing Protocol	HRCMA

A flat topology of 1000 x 1000 m^2 was taken as area for experimentation involving a random distribution of 100 nodes. Each node was configured with an initial energy of 10J. the performance metrics taken for justifying the superiority of proposed method include the throughput, latency measured on an end-end basis, residual energy, energy consumption per node after one iteration of transmission and the packet delivery ratio analysis. These metrics have been compared against recent and benchmark methods namely PSO (Particle Swarm Optimization), ACO (Ant Colony Optimization), GWO (Glow Worm Optimization) which was also experimented in this work. The distribution scenario of the proposed WSN is shown below in **Fig. 5**.

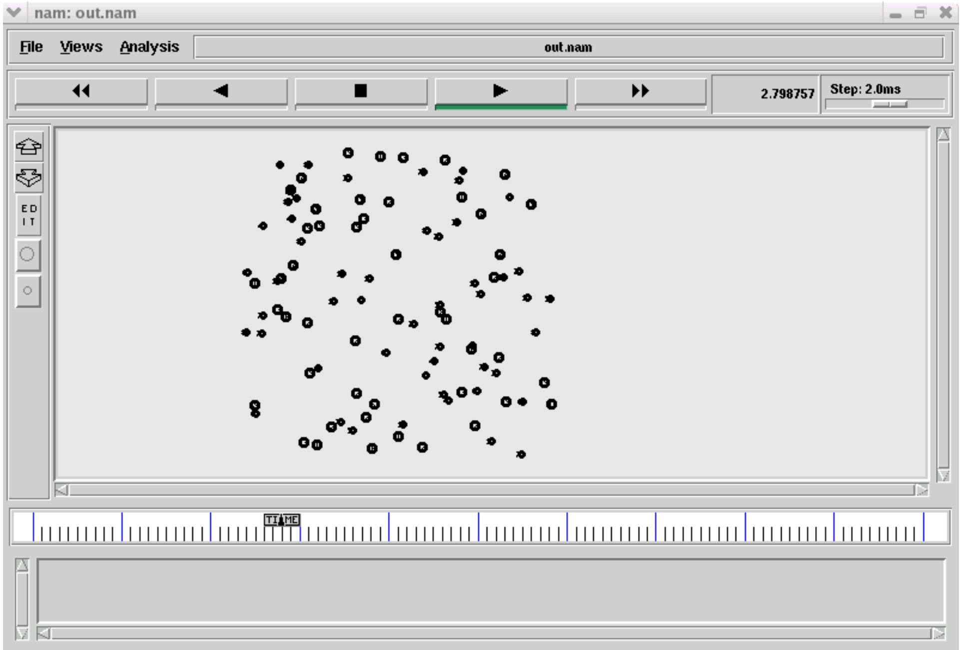

Fig. 5. Node distribution scenario in proposed WSN network model

As mentioned in previous sections, three metrics namely residual energy, distance to base station and traffic density is taken for the route maintenance. FDE is used to arrive at a decision related to retaining or updating a new node. A set of 49 fuzzy rules are formulated along with the membership functions. The rule base is depicted in **Table 2** shown below.

Table 2. Fuzzy rule in proposed HRCM model

M_{Er}	M_d	M_{tr}
L	L	L
L	L	H
L	H	L
L	H	H
M	L	L
M	L	H
M	H	L
.	.	.
.	.	.
.	.	.
H	H	L
H	H	H

An essential condition in proposed HRCM is that, only if all the three metrics exhibit optimality, the node is retained. Else, the next node is selected. As mentioned in previous sections, the ACO create module is invoked once two subsequent nodes fail to satisfy the FDE. The membership functions utilized are triangular in nature based on the three metrics. The triangular function is depicted in **Figs. 5 – 7** shown below.

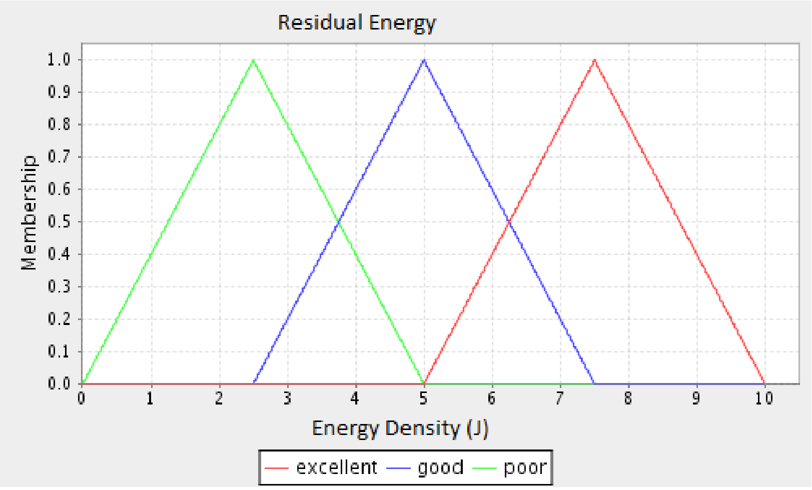

Fig. 6. MF for residual energy of Nth node at time T

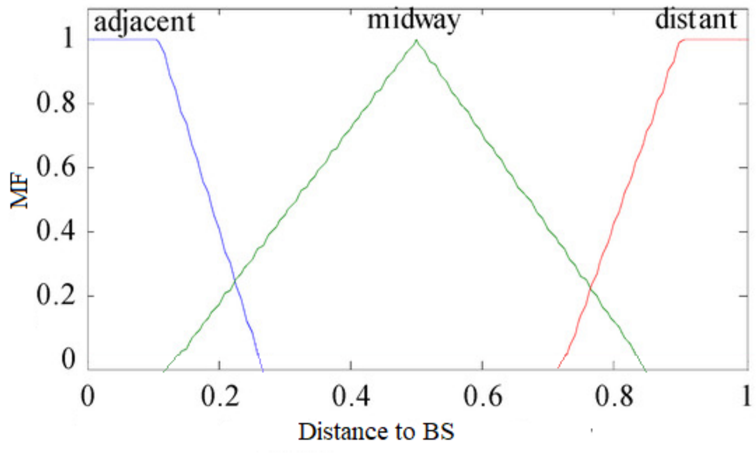

Fig. 7. MF for distance of Nth node to BS at time T

Unlike the other two MFs as shown in **Figs. 6-7**, the MF for packet density cannot be strictly triangular due to dynamic nature of variation of input traffic packets. Hence, a Gaussian MF is selected as its behavior better suits the incoming traffic pattern. The MF for the packet density observed over a period of time is shown in **Fig. 8**. Up to 300 packets of streaming data are light load while an average incoming load is fixed at traffic up to 400 packets while those exceeding 400 on a continued basis are termed to be high loading conditions.

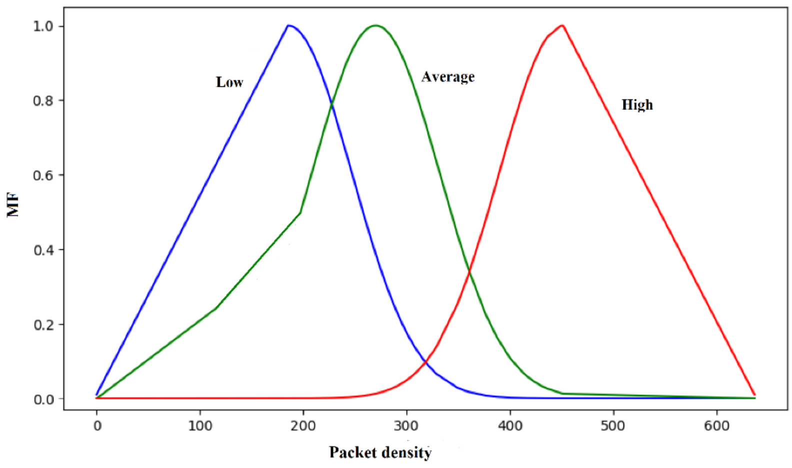

Fig. 8. MF for packet density at time T

4.3 Discussion on the results

Based on the MFs and fuzzy rule base formulated and depicted earlier, performance metrics such as throughput, packet delivery ratio and end-end delay are observed and projected in **Figs. 9 - 11**. The throughput observed is projected in **Fig. 9** shown below.

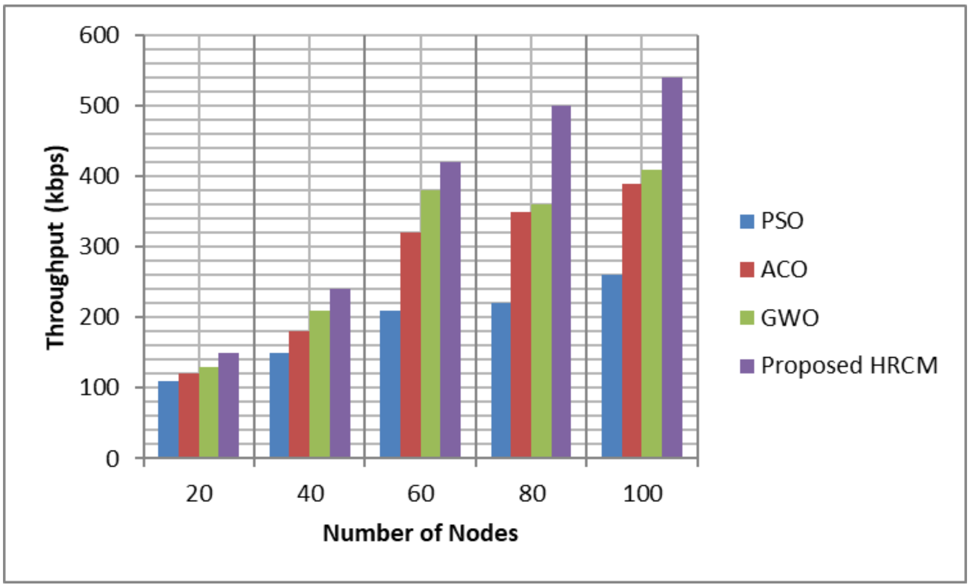

Fig. 9. Throughput analysis of proposed HRCM routing model

Fig. 9 clearly depicts the superior performance of proposed HRCM over conventional benchmark methods with an improved throughput of nearly 540kbps over the 260kbps observed for PSO. The accelerated throughput observed in **Fig. 9** in proposed work namely HRCM is attributed to the dedicated route discovery and maintenance protocol, which is missing in the for PSO, ACO and GWO models.

The end-end delay or the latency in the proposed work is observed and projected against PSO, ACO and GWO models and depicted in **Table 3** shown below.

Table 3. Latency Analysis

Methods	Number of nodes				
	20	40	60	80	100
PSO	60	80	110	140	210
ACO	40	50	65	100	140
GWO	30	60	60	90	110
Proposed HRCM	20	45	50	80	100

It could be observed from **Table 3** that the delay tends to increase beyond 150s for PSO model for increasing node count which is attributed to increased waiting time of packets which consequently results in packet loss increase. The drastic increase in delay in PSO is basically due to the fact of failing links which do not have an automated route maintenance mechanism where in the proposed HRCM has a dedicated fuzzy rule working on the link selection and maintenance by monitoring it in a continuous manner. In the case of PSO model, the cluster head is not able to continuously monitor the status of the link once it is established. If included, the time taken to monitor them through broadcast packets considerably is higher as compared to proposed HRCM.

Table 4. Delay vs Packet Analysis

Methods	Number of packets				
	2	4	6	8	10
PSO	31	42	80	90	158
ACO	24	40	60	80	100
GWO	21	37	59	70	88
Proposed HRCM	19	23	41	60	69

The proposed HRCM mode exhibits a reduced latency for increasing number of nodes indicating quick communication of packets from source to destination which in turn reflects the high reliability and trustworthiness of the nodes in the proposed ACO path create model. The increased latency observed in other methods is primarily attributed towards link or node failures. A similar scenario is projected in **Table 4** where the delay due to dynamically varying packet or traffic scenario is established. It could be observed that proposed HRCM model exhibits reduced latency even in times of increased overhead due to incoming packets of information. It could be observed that at a nominal packet count of 5 packets/s, improvement in latency is over 25% over ACO, 13% over PSO. An analysis of packet drop ratio is projected in **Table 5** shown below.

Table 5. Packet Drop Analysis

Methods	Time duration (s)				
	200	400	600	800	1000
PSO	620	680	810	980	1200
ACO	500	670	770	900	1020
GWO	480	600	640	780	970
Proposed HRCM	390	470	630	760	780

The above simulation is done with respect to simulation time or rounds where increasing time results in considerable amount of loss of packets due to the delay or waiting time. Amongst existing benchmark methods, a minimal packet drop is observed for proposed HRCM which indicates the superior quality of nodes and links selected by the ACO and maintained by the FDE module. As a reflection of the fact that both PSO, ACO and GWO have no specific attention towards route creation or maintenance but consider them as an integrated component, the links are quite not stable enough due to which considerable number of packets tend to get to be dropped as shown in **Table 5** which is very minimal in the case of proposed HRCM.

A final comparison of energy consumed during the communication process is observed and projected in **Table 6**. Two different cases have been simulated. The first case in **Table 6** projects the variation of energy consumption with increasing node count in the routing path while that of in **Table 7** projects the energy consumption with increasing packet (incoming traffic). As observed in **Table 6**, the increasing number of nodes provides a considerable overhead for PSO, ACO and GWO models where the time taken to form a cluster head based on a similarity measure is considerably higher.

Table 6. Energy Consumption Analysis (Case I)

Methods	Number of nodes				
	20	40	60	80	100
PSO	1.8	2.4	2.8	4.4	6
ACO	1.1	2.7	2.2	3.8	3.9
GWO	1	2.6	2	2.4	2.8
Proposed HRCM	0.9	2.4	1.8	2.1	2.3

In case I scenario, the energy consumption against number of nodes in the routing path is considered. Increasing node count subsequently causes an increase in energy consumption/node thus contributing to the overall increase in energy consumption. Moreover, in addition to above mentioned overhead, the increase in energy consumption is attributed to power being utilized by idle nodes which do not take part in the communication process as there is not specific methodology to address it in PSO, ACO and GWO models. However, in the proposed model, the list of nodes required for communication are selected by optimal selection model namely the ACO resulting in drastic reduction in energy consumption.

Table 7. Energy Consumption Analysis (Case II)

Methods	Number of packets				
	200	400	600	800	1000
PSO	2.5	3.5	4.1	5.4	7.1
ACO	1.9	2.9	3.9	4.9	6.2
GWO	1.4	2.1	3.2	4.5	5.9
Proposed HRCM	0.9	1.7	2.9	3.4	4.8

Case II scenario is simulated against varying traffic scenario by increasing the number of incoming packets of information on the routing path selected by ACO. It could be observed that a 18% reduction in energy consumption at peak packet rate of 1000 packets is observed for proposed HRCM over the ACO and 12% reduction as compared against PSO and GWO routing methods. Increased number of packets or traffic volume demands best route creation having high residual energies of cluster heads which is not taken into account in conventional PSO, ACO and GWO models. However, in the proposed HRCM model, the ACO initializes its operation with computation of initial energy of cluster heads and continues to monitor it at the end of each transmission cycle thus maintaining the link stability. In case, the residual energy drops below the set threshold, the fuzzy rule engine is invoked to determine the next possible candidate for cluster head selection. This two-phase rule thus accounts for reduced energy consumption even with increasing traffic.

5. Conclusion

Energy efficient routing is taken as the primary objective in this research work and the performance of a non-cluster-based routing method is compared against cluster-based routing methods. A route-create and maintain routing method utilizing the combined benefits of meta-heuristic ACO and Fuzzy decision module is proposed and implemented for a WSN network scenario. Cluster based method offer an efficient energy efficient routing solution but tend to increase in complexity and computational cost in scenarios of dynamically varying environmental conditions like increased bandwidth, users etc. a simple and effective solution is proposed in this research paper through a two-phase methodology where a reliable path is created using the optimization property of ACO and the path is maintained by a continued monitoring and update of fuzzy decision engine based on the network configuration parameters which is entirely dependent on the input load conditions. Throughput, energy consumption, packet drop analysis and delay have been the prime metrics taken for valuation as they strongly reflect the reliability of the link and nodes in the routing path. Superior performance is observed in each case when compared with PSO, ACO and GWO models thus indicating an improved lifetime owing to reduced energy consumption by nodes as validated from the observed results. As a future scope, an intrusion detection mechanism [39] integrated into this platform will aid to ward of mitigation attacks which may further contribute to improvement of QoS. Research towards utilization of this routing protocol towards high data rates which are characteristic of evolving 5G communication standards are also taken to be critical points for future improvement of this work. Invoking the proposed energy efficient routing in medical data [40] also is quite an evergreen area of research.

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