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Intelligent energy-aware efficient routing for MANET

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Abstract Designing an energy efficient routing protocol is one of the main issue of Mobile Ad-hoc Networks (MANETs). It is challenging task to provide energy efficient routes because MANET is dynamic and mobile nodes are fitted with limited capacity of batteries. The high mobility of nodes results in quick changes in the routes, thus requiring some mechanism for determining efficient routes. In this paper, an Intelligent Energy-aware Efficient Routing protocol for MANET (IE2R) is proposed. In IE2R, Multi Criteria Decision Making (MCDM) technique is used based on entropy and Preference Ranking Organization METHod for Enrichment of Evaluations-II (PROMETHEE-II) method to determine efficient route. MCDM technique combines with an intelligent method, namely, Intuitionistic Fuzzy Soft Set (IFSS) which reduces uncertainty related to the mobile node and offers energy efficient route. The proposed protocol is simulated using the NS-2 simulator. The performance of the proposed protocol is compared with the existing routing protocols, and the results obtained outperforms existing protocols in terms of several network metrics.

Keywords Mobile ad-hoc network · Multi-criteria decision making · Soft set · Fuzzy soft sets · Intuitionistic fuzzy soft sets

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1 Introduction

Mobile Ad-hoc Networks (MANET) is an active, self-structuring network [1–3] which is a collection of active nodes moving freely. This node has has its own radio range [4]. However, mobile nodes may fail to spread the information due to limited radio range in some scenarios. Similarly, if the transmission reaches its respective radio ranges, it is retained by setting up next hop as a mediator. This helps to maintain wireless environments and applications [5]. This is achieved in two ways: single-hop transmission and multi-hop transmission. In recent years, dynamic nature of MANET, has pervaded into world-wide applications such as Industry sector for e-commerce [6], Environmental monitoring [7], Vehicular networks, Bluetooth, Personal area network, Military usages, Disaster Management and otehrs.

The energy source for MANET communicative devices heavily rely on rechargeable battery, whose capacity poses restriction on network lifetime as well as network performance by influencing several network metrics [8, 9].

Energy efficiency provides same services by using less energy. To achieve this purpose, the proposed protocol designed an energy efficient routing protocol under the multi-constrained criteria. It deals with multiple conflicting conditions to evaluate a decision. This decision is made by combining two approaches such as Intuitionistic Fuzzy Soft Set (IFSS) and Multi Criteria Decision Making (MCDM) [10]. IFSS is a combination of Intuitionistic Fuzzy Set (IFS) and soft set. IFS [11] is an extension of fuzzy set (i.e. fuzzy logic). Fuzzy logic [12, 13] is associated with the point based membership function. It represents several uncertainties and imprecise knowledge (i.e. resource, mobility, channel, traffic load, routing, etc.) efficiently. It reduces the effect of mutual interference among routes and nodes. Hence, it easily handles the high unpredictability of situation during route discovery and maintenance [14, 15], whereas IFS is associated with an interval-based membership function which is more expressive than point based membership function in capturing vagueness of the data in any domain. Therefore, it is better than fuzzy set and also has the strong ability of describing uncertainties of the network. Soft set theory has better ability to deal with multi-constrained criteria or parameters efficiently in MCDM environment. A combination of both, provides a technique (i.e. IFSS) to model the recognition of imprecise knowledge.

To enhance the performance of IE2R, the above mentioned key points are theoretically evaluated and analyzed. Finally, simulation results shows that the proposed protocol outperforms existing protocols in terms of several network metrics. More details about these points are elaborated in the later sections.

1.1 Motivation

The selection of energy efficient routing is an essential issue due to limited capacity of batteries. In the last few decades, two types of energy efficient routing protocols have been proposed: (1) Non-approximate reasoning based approach, and (2) Approximate reasoning based approach.

1. Non-approximate reasoning based approaches [16–19] consider only energy parameter of the network, they do not consider other parameters that affect on the network lifetime. These approaches are unable to reduce mutual interferences among nodes as well as different uncertainties related to the network information. Due to this limitation, the performance of network metrics drastically degrades.
2. Approximate reasoning based approaches [20–23] consider both parameters (i.e. energy and mutual interference). But these cannot consider other parameters like hop-count, packet, delay and distance. Hence, network lifetime cannot evaluate precisely as well as communication overhead increases.

Compared to above mentioned approaches, the IE2R gives state-of-the-art technology that incorporates a combination of IFSS with MCDM to achieve the advantages of both. The integration of both techniques offers a novel ability, that qualitatively detect the characteristics of a routing system. It is more expressive in capturing vagueness of network resources and achieves inherent robustness of network metrics.

1.2 Contributions

The combination method of IFSS with MCDM provides a mathematical framework for analyzing and modeling decision making problems more precisely. However, no prior work has been done on the integration of both approaches. Hence, the proposed protocol arrives to overcome this gap. The key contributions of this paper are as follows:

1. Some of the nodes such as simple node, junction node, fictitious node, source node (opening node) and deceased node are illustrated which play vital role in route discovery and maintenance as well as enhance the network lifetime.
2. Defining Route REQuest (RREQ), Route REPly (RREP), Route ERRor (RERR) and HELLO packet for route handling and communication with non-pruned neighbors.
3. Defining several parameters or indicators (e.g. hop-count, packet, residual energy, delay and distance) based on IFSS approach and these parameters play a special role in the MCDM environment along with the moderate assessment of the furnished data.
4. Selection of neighbour nodes based on the messages that are provided by the nodes.
5. Defining route maintenance scheme which handles link and node failure in-time, before they crash.
6. Determination of energy efficient routes with the help of MCDM by following the steps.
   a. Identifying the goal of the decision making process (i.e. selection of energy efficient route).
   b. Selection of the indicators (i.e. parameters) and the routes.
   c. Assigning weights to each parameter based on entropy weighting method.
   d. Assigning outranking to each and every route based on PROMETHEE-II aggregating method.
7. The integration approach helps to reduce the mutual interferences between nodes and eliminate uncertainties related to route selection.
8. Finally, network lifetime is increased by using several network metrics.

1.3 Organization of the paper

The remainder of this paper is organized as follows. In Sect. 2, literature reviews are presented. In Sect. 3, general ideas of several preliminaries are discussed. Section 4 analyzes mathematical model of intuitionistic fuzzy soft sets and its related components. The different terminologies used in this proposed protocol are described in Sect. 5. The concise description of the proposed protocol and its inherent phases are described in Sect. 6. Section 7 demonstrates the performance evaluation of the proposed protocol via simulations and analyzes the obtained results in detail. Finally, conclusion and future enhancements are outlined in Sect. 8.

2 Literature review

Routing problem is the main issue in MANET due to infrastructure-less behaviour. In this section, two types of energy efficient routing protocols have been discussed as non-approximate reasoning based approach and approximate reasoning based approach. Explanation of these approaches are mentioned below:

2.1 Non-approximate reasoning based routing protocols

Here, some related works are discussed covering with non-approximate reasoning based approaches, such as Sridhar et al. [16] proposed an ENergy-enabled AODV protocol (EN-AODV). In this protocol, energy is announced with the help of sending and receiving capacities of nodes and the amounts of the packet to be transmitted. Moreover, routing path is selected by computing the energy level of each node.

Gu and Zhu [17] proposed a power conscious routing protocol, which concurrently meets two aims in the route discovery phase, such as minimum hops and maximum Route Energy Comprehensive Index (RECI) value. Finally, it obtains some actions to protect the source and destination nodes to prolong the lifetime of the network at the time when their energy is low.

Lou and Zhuang [18] proposed an ENergy Efficient Opportunistic Routing (EEOR). In this routing, the authors apply sleep scheduling at the link layer. The foremost goal of applying scheduling is to increase energy efficiency. The authors also identify an exchange between the transmitted energy at the sender level with more than one receiver level.

Ravi and Kashwan [19] proposed an algorithm Energy-Aware Span Routing Protocol (EASRP) for reactive protocol. It employs two power reduction schemes as Span and Adaptive Fidelity Energy Conservation Algorithm (AFECA). Afterwards, Remote Activated Switch (RAS) hardware circuit is used to optimize energy level by enabling disabled nodes. This algorithm is designed for reactive protocols.

The above mentioned approaches have some limitations that does not deal with different uncertainties related to the network information.

2.2 Approximate reasoning based routing protocols

Here, some other related works are discussed covering approximate reasoning based approaches, such as Abirami et al. [20] proposed a fuzzy logic approach for obtaining energy enabled path during the route discovery method. In this approach, two parameters are used such as power consumption and battery cost for designing optimal routes.

Hiremath and Joshi [21] suggested an alterable energy efficient routing protocol. The basic aim of this protocol is to forward RREQ packet with the help of fuzzy residual energy. The residual energy is measured by using a threshold value chosen by the decision maker.

Chettibi and Chikhi [22] planned a new pro-active energy efficient routing protocol and is based on Optimized Link State Routing protocol (OLSR). It used fuzzy logic to adjust two parameters (e.g. residual network lifetime and residual energy). It also used adaptive data traffic to enhance network robustness.

Chettibi and Chikhi [23] proposed a routing protocol based on fuzzy logic. It deals with energy issue by modification of AODV protocol. It incorporates two changes of AODV: Dynamic Fuzzy Energy State based AODV (DFES-AODV) and Fuzzy State Action Reward State Action based AODV (FSARSA-AODV). The combination of both deals with uncertainties and overcomes the issues that was observed in State Action Reward State Action based AODV (SARSA-AODV) protocol.

Carvalho et al. [24] designed a cross layers routing for hybrid mobile ad-hoc network. It used fuzzy based mechanism for all layers by employing two input parameters, energy and mobility. It offers better quality of network resources and enhanced lifetime of the network. It consists of a decision metric in each layer based on Quality of Service (QoS) and Quality of Experience (QoE) to enhanced network lifetime and energy efficiency.

Sarkar and Datta [25] proposed an energy efficient multi-path routing protocol for MANET based on stochastic method. It computes multiple routes between source and destination nodes and select an energy efficient path stochastically. In this protocol, information is exchanged randomly. During flooding, it helps to secure data packet based on stochastic method.

Das and Tripathi [26] designed a routing protocol that chooses an energy efficiency route based on vague set. It employed two interval-based membership function for energy and distance parameter. It helps to reduce interference among nodes and select energy efficient route based on true and false membership functions.

The above mentioned approaches considered several uncertainties of network information but did not considered some parameters apart from residual energy such as hop-count, transmitted packet, delay and distance. Hence, these proposal does not enhance network lifetime precisely.

3 Preliminaries: concepts and definitions

In this section, some preliminaries are discussed which provide a detailed analysis of the proposed routing protocol.

3.1 Multi-criteria decision making

MCDM is a sub-discipline that explicitly considers multiple criteria in decision making environments. According to the authors [27], it is divided as: Multi-Attribute Decision Making (MADM) and Multi Objective Decision Making (MODM). MADM deals with discrete decision spaces where the set of decision is predetermined. MODM deals with several decision problems in which decision space is continuous. For instance, mathematical problems with multiple objective functions.

3.2 Expert system

Expert system or decision maker [28] is a part of artificial intelligence having vast knowledge in a precise domain. It has two basic elements: knowledge based system and inference engine. The purpose of first element is to resolve any problem in intellectual way. The purpose of second element to evaluate the data using a rule based system.

3.3 Routing protocol in ad-hoc network

Routing is a primary component of any network and responsible for several operations between source and destination nodes. This is a mechanism for finding an optimum route in order to transfer the message. It divided into three parts as shown in Fig. 1.

3.3.1 Proactive routing protocol or table driven approach

This routing protocol maintains a regular and up to date routing information about each and every path by spreading route updating scheme at fixed time intervals. Example of proactive routing protocols are Destination Sequenced Distance Vector Routing (DSDV), Optimized Link State Routing (OLSR) and Wireless Routing Protocol (WRP).

3.3.2 Reactive routing protocol or on demand driven protocol

This routing protocol establishes the route for transmission only when there is a demand. Example of reactive routing protocols are Ad Hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Associativity Based Routing (ABR).

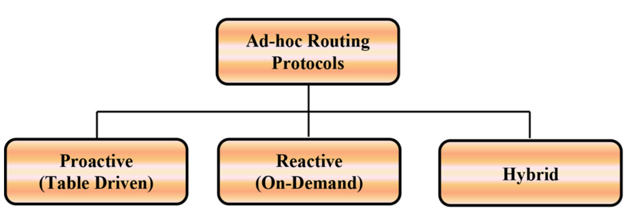

Fig. 1 MANETs routing protocols

3.3.3 Energy based AODV protocol

The proposed protocol IE2R is based on the Energy-enable AODV protocol (EN-AODV). In this protocol, first energy is calculated then sending rate, receiving rate and size of the packets are justified. The nature of this protocol is on demand routing protocol. It discovered route by using of RREQ and RREP packet. A threshold value is defined for selection of routing; the route is selected only if its energy level is more than a threshold value.

3.3.4 Hybrid routing protocol

It is an association of proactive and reactive protocols. In this protocol, a route is established with the help of proactive method and uses a reactive method for flooding of different mobile nodes. Example of hybrid routing protocols are Temporary Ordered Routing Algorithm (TORA), Zone Routing Protocol (ZPR) and Order One Routing Protocol (OOPR).

4 Mathematical model of IFSSs and its related components

There are several components related to IFSSs such as fuzzy logic, soft set, fuzzy soft set, and intuitionistic fuzzy set. Short mathematical illustrations of these components are given below:

Definition 4.1: (***Fuzzy logic***) Fuzzy logic is a constituent element of soft computing [29, 30]. It is a science of reasoning which deals with linguistic variable. A fuzzy set $\mathrm{F} = \{<\mathrm{u}, \mu_A(\mathrm{u}) > |\mathrm{u} \in \mathrm{U}\}$ in a universe of discourse U is characterized by a membership function, μ_A, as follows: $\mu_A : \mathrm{U} \to [0, 1]$.

Definition 4.2: (***Soft set***) Let U be an initial universe set and E is a set of parameters. A pair (F, A) is a soft set [31] over U, when $A \subseteq E$ and $F \to P(U)$, where P (U) denotes the set of all subsets of U. For illustration, let us consider the following example.

Example 4.1: Let U be a set of four cars {Toyota, Tata, Maruti, Honda} given by $\mathrm{U} = \{c_1, c_2, c_3, c_4\}$ and E is a set of parameters given by E = {White color, Red color, Diesel engine, Petrol Engine} $= \{p_1, p_2, p_3, p_4\}$.

Let $A = \{p_1, p_3\} \subset$ E. Now consider that $F_{\{A\}}$ is a mapping given by, $F_{\{A\}}(p_1) = \{c_1\}, F_{\{A\}}(p_3) = \{c_1, c_4\}$.

Then the soft set $(F_{\{A\}}, E) = \{(p_1, \{c_1\}), (p_2, \{\phi\}), (p_3, \{c_1, c_4\}), (p_4, \{\phi\})\}$.

Definition 4.3: (***Fuzzy soft set***) Let U be an initial universe set and E is a set of parameters given by $E = \{A \cup B \cup C\}$ where A, B, C are sets of different linguistic variables. All pairs $(F_1, A), (F_2, B), (F_3, C)$ are a fuzzy soft set [32] over U when $A \subset E, B \subset E, C \subset E, (A \cup B \cup C) = E$, $F_1 : A \to FS(U), F_2 : B \to FS(U), F_3 : C \to FS(U)$, where FS (U) denotes the set of all fuzzy sets on U. For illustration, let us consider the example given below.

Example 4.2: Let U be a set of three mobile cell phones {Micromax Canvas, Samsung Galaxy, Celkon Diamond} given by U = {m_1, m_2, m_3}. It has different colors, prices, and features. The color is represented by A = {Red color (c_1), Blue color (c_2), Pink color (c_3)}. The price is represented by B = {Low price (p_1), Medium price (p_2), High price (p_3)}. The feature is represented by C = {Bad (f_1), Average (f_2), Good (f_3)}. The universal set of parameters is E = {A ∪ B ∪ C}.

A fuzzy soft set (F_1, A) describes the "mobile cell phone having different colors" as $F_{1_{\{A\}}}(c_1) = \{m_1/0.3, m_2/0.4, m_3/0.1\}$, $F_{1_{\{A\}}}(c_2) = \{m_1/0.8, m_2/0.2, m_3/\ 0.3\}$, $F_{1\{A\}}(c_3) = \{m_1/0.9, m_2/0.5, m_3/0.4\}$. A fuzzy soft set ($F_2$, B) describes the "mobile cell phone having different prices" as $F_{2_{\{B\}}}(p_1) = \{m_1/0.7, m_2/0.4, m_3/0.2\}$, $F_{2_{\{B\}}}(p_2) = \{m_1/0.9, m_2/0.3, m_3/0.7\}$, $F_{2_{\{B\}}}(p_3) = \{m_1/0.1, m_2/0.5, m_3/0.4\}$. A fuzzy soft set ($F_3$, C) describes the "mobile cell phone having different features" as $F_{3_{\{C\}}}(f_1) = \{m_1/0.9, m_2/0.6, m_3/0.8\}$, $F_{3_{\{C\}}}(f_2) = \{m_1/0.2, m_2/0.5, m_3/0.4\}$, $F_{3_{\{C\}}}(f_3) = \{m_1/0.7, m_2/0.5, m_3/0.3\}$.

Definition 4.4: (***Intuitionistic fuzzy set***) Intuitionistic fuzzy set is an extended fuzzy set which is a part of soft computing. It allows approximation of human reasoning [31, 32]. Let A is an intuitionistic fuzzy set given by A = { < u, μ_A (u), ν_A (u), π_A (u) > | u ∈ U} in a universe of discourse U is characterized by true membership function (μ_A), false membership function (ν_A) and hesitation membership function (π_A) as follows: μ_A: U → [0, 1], ν_A: U → [0, 1], π_A: U → [0, 1] and $0 \leq (\mu_A + \nu_A + \pi_A) \leq 1$.

Definition 4.5: (***Intuitionistic fuzzy soft set***) Let E is a group of parameters for preliminary universe set U. Let IF^U signify the group of all intuitionistic fuzzy subsets of U. Let A ⊂ E, where a pair (F, A) is called Intuitionistic Fuzzy Soft Sets (IFSSs) [33] over U, where F is a mapping given by F: A → IF^U.

Example 4.3: Let U and E remain same as the Example 4.2. Here, A is a set defined as A={c_1, c_2, c_3} ⊂ E. Now suppose that an IFSS (F_1, A) describes the "mobile cell phone having different colors" as $F_{1_{\{A\}}}(c_1)$ = {m_1/(0.3, 0.5, 0.2), m_2/(0.4, 0.1, 0.5), m_3/(0.1, 0.4, 0.5)}, $F_{1_{\{A\}}}(c_2)$ = {m_1/(0.7, 0.2, 0.1), m_2/(0.2, 0.7, 0.1), m_3/ (0.4, 0.3, 0.3)}, $F_{1_{\{A\}}}(c_3)$ = {m_1/(0.8, 0.1, 0.1), m_2/(0.5, 0.4, 0.1), m_3/(0.4, 0.4, 0.2)}.

5 Terminologies used in the proposed protocol

Let ξ is a set of all type of 'n' nodes given as $\xi = \{N_1, N_2, N_3, \ldots\ldots N_a, N_{a+1}, \ldots\ldots N_b, N_{b+1}, \ldots\ldots N_c, N_{c+1}, \ldots\ldots N_n\}$. In the proposed model, there are six kinds of nodes and three kinds of routes which are being used. The six kinds of nodes are *"simple node* (N_s)", *"junction node"* which is further divided as *"permanent junction node* (N_{PJn})" and *"temporary junction node* (N_{TJn})", *"fictitious node* (N_f)", *"source node* (N_{SRn})", and *"deceased node* (N_d)". The three kinds of route are *"node disjoint route"*, *"link disjoint route"* and *"non-disjoint route"* are define as follows:

Definition 5.1: (***Simple node***) Simple nodes are energy enabled mobile nodes. Simple set is the set of simple nodes within network indicated as N_{set1}. It is obvious that a mobile node N_s belongs to N_{set1} if it fulfills the following criteria:

$$N_s \in N_{set1} \Longleftrightarrow [\{N_i \in E_{enable}(N_s) | N_i \in \xi\} \wedge \{N_j \notin E_{enable}(N_s) | \forall N_j \in (\xi - N_i)\}]$$

where $E_{enable}(N_s)$ is the set of energy enable node and ξ is the set of all mobile nodes.

Definition 5.2: (***Junction node***) It is a collection of highest energy enabled node. It works as a turning point that indicates if any node N_{i+1} fails than node N_i sends data packet through another link.

Definition 5.3: (***Permanent junction node***) This junction node has fixed number of routes to destination. Permanent junction set is the set of all permanent junction nodes referred as N_{set2}. It is obvious that a mobile node N_{PJn} belongs to N_{set2} if it fulfills the following criteria:

$$N_{PJn} \in N_{set2} \Longleftrightarrow [\{N_i \in E_{hign}(N_{PJn}) | N_i \in \xi \text{ and } E_{high}(N_{PJn}) > E_{enable}(N_s)\} \wedge \{N_i \in M_{link}(N_{PJn})\}]$$

where E_{high} (N_{PJn}) is the set of high energy enabled nodes which has more energy than the simple nodes and M_{link} (N_{PJn}) is the set of multi-link nodes.

Definition 5.4: (***Temporary junction node***) The simple node works as temporary junction if its preceding node behaves as malicious node referred as N_{set3}. It is obvious that a mobile node N_{TJn} belongs to N_{set3} if it fulfills the following criteria:

$$N_{TJn} \in N_{set3} \iff [\{N_i \in E_{hign}(N_{TJn}) | N_i \in \xi \; and \; E_{high}(N_{TJn}) > E_{enable}(N_s)\} \wedge \{N_i \in S_{link}(N_{TJn})\}]$$

where E_{hign} (N_{TJn}) is the set of high energy enabled nodes which has more energy than the simple nodes and S_{link} (N_{TJn}) is the set of single link (excluding the failure link) nodes.

Definition 5.5: (***Deceased node***) The deceased node is a malfunctioned node due to insufficient energy referred to as N_{set4}. It is obvious that a mobile node N_d belongs to N_{set4} if it fulfills the following criteria:

$$N_d \in N_{set4} \iff [\{N_i \in E\phi(N_d) | N_i \in \xi\}]$$

where Eϕ (N_d) is the set of blank energy enable nodes and ξ is the group of all mobile nodes.

Definition 5.6: (***Fictitious node***) The fictitious node is a virtual node which is used to hide the address of the original node. This node does not contains the routing information. It helps to prevent any attack. It only gives the message to the mentor about network status and attacker. It is referred to as N_{set5}. It is obvious that a mobile node N_f belongs to N_{set5} if it fulfills the following criteria:

$$N_f \in N_{set5} \iff [\{N_i \in R\_table\phi(N_f) | N_i \in \xi\} \wedge \{N_j \in E_\phi(N_f) | N_j \in \xi\}]$$

where $R\_table\phi$ (N_f) is the set of node which has no R_{table} (Routing table), $E_\phi(N_f)$ is the set of null energy enable node and ξ is the set of all mobile nodes.

Definition 5.7: (***Source node***) The source node is a node where RREQ is generated at first; generally a source node is an opening node. It is referred to as N_{set6}. It is obvious that a mobile node N_{SRn} belongs to N_{set6} if it fulfills the following criteria:

$$N_{SRn} \in N_{set6} \iff [\{N_i \in E_{enable}(N_{SRn}) | N_i \in \xi\} \wedge \{N_j \in E_{enable}(N_{SRn}) | \forall N_j \in (\xi - (N_{set1} \cup N_{set2} \cup N_{set3} \cup N_{set4} \cup N_{set5}))\}]$$

where, $E_{enable}(N_{SRn})$ is the group of energy enabled nodes and ξ is the group of all mobile nodes.

Definition 5.8: (***Node disjoint route***) Two or more routes are node-disjoint if they have no node in common excluding the source and the destination nodes. In Fig. 2(a), node disjoint routes are {ADB}, {AEB} and {ACB}.

Definition 5.9: (***Link disjoint route***) Two or more routes are link-disjoint if they have no link in common. In Fig. 2(b), link disjoint route are {ADECB} and {AEB} because node E is common, but no link is common.

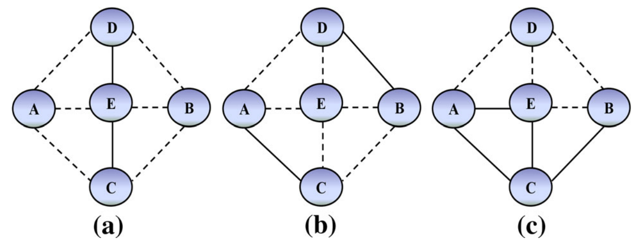

Fig. 2 Different types of routes

Definition 5.10: (***Non-disjoint route***) Two or more routes are non-disjoint route if they have a node or link in common. In Fig. 2(c), non-disjoint routes are {ADECB} and {AEB} because node E is common but no link is common.

6 IE2R: intelligent energy-aware efficient routing for MANET

6.1 Overview

The proposed protocol is based on total five phases. Each and every phase plays significant role to achieve motive of the proposed protocol. Developmental stages of the proposed protocol are shown in Fig. 3. It consists of three

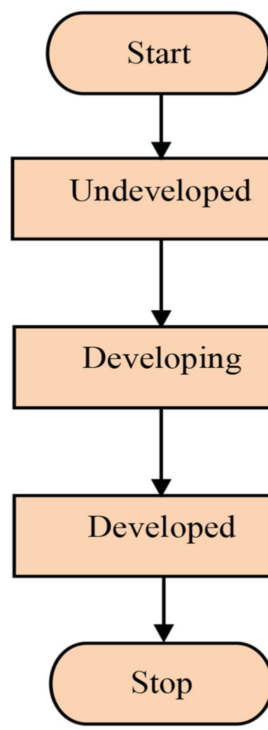

Fig. 3 Stages of the proposed protocol

stages such as undeveloped, developing and developed. Undeveloped stage is the pre-stage of the route discovery process which contains two phases: network information model and route initiation. Developing stage consists of two phases: route discovery and route maintenance. The final stage,i.e., developed, consists of one phase: route selection, where energy efficient route is uniquely selected with the helps of expert system.

6.2 The network information model

This phase contains several sub-phases which help to illustrate network information model briefly.

6.2.1 Network region

The proposed network region is divided into two parts named as, "*Operational Region*" and "*Deceased Region*" as shown in Fig. 4.

1. ***Operational region:*** This region is a workable area which is used to communicate several operations smoothly.
2. ***Deceased region:*** This region is non-workable area which is inoperative due to several causes.

6.2.2 Causes behind deceased region

There are numerous causes behind deceased region, some of them given below.

a. Numerous natural calamities such as flood, storm, earthquakes, tsunami, tornados, etc.
b. If nodes are too far apart due to malicious phenomenon then many nodes would be isolated and data would not reach to proper destination.
c. If nodes are too close due to any reason then the area covered would be a small and less amount of information would be retrieved.
d. Most of the real life applications deal with a heterogeneous network environment which is partially difficult to handle.

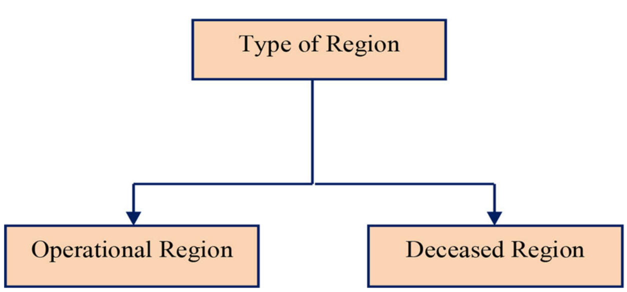

Fig. 4 Type of region

6.2.3 Effects of deceased region

The operational region is changed into deceased region when several natural hazards (e.g. volcano explosions, earthquakes, storms, floods, etc.) becomes natural disasters. The change reflects on the population of people. Then communication is completely cut off. It creates huge loss to the mission and no information will be communicated. Therefore, the result will reach to zero level support. At this time, setting up a new communication system is impossible due to high cost that cannot be sustained.

For instance, to complete any operation 'n' nodes are required. But at the time of any natural calamity, if 'k' (range of k is $0 \leq k \leq n$) nodes are destroyed, the network undergoes breakdown. At this time, following three cases are possible:

Case 1: If k = 0 then, there is no need for random deployment.

Case 2: If k = 1, 2, 3 ...n where $k << n$, then, there is need for random deployment.

Case 3: If k = n then, operational region again becomes deceased region.

6.2.4 Random deployment

It is a solution to overcome several problems with deceased region. It is a systematic method of using effective skills of organization, administrative decisions, several policies and strategies. In random deployment, initially user plans to setup the operational region by using $m = n + k$ nodes. At the time of operation, 'n' nodes will be planned for communication system. Remaining 'k' nodes are stored as impending nodes, which are in inactive mode initially. At the time of random deployment, the 'k' destroyed nodes were replaced by impending 'k' nodes. These nodes help to resume the operation. In this way, non-workable area serves as a workable area.

6.2.5 The proposed operational region

The proposed operational region is modeled as a graph G = (V, E). Here, V is the set of nodes and E is the set of full-duplex edges. Any node may sometimes be mobile or stationary based on operation. For instance, each node attached to an object which is movable in any environment like shopping mall, airport, factory, hospital, etc. The locations of the vertices V and the edges E changes time to time during communication. Because nodes frequently join and leave from one range to another range. But sometimes based on requirement, it is also left in a fixed position for a short period. The set of nodes V locates in a L_R X L_R region randomly. Each node has a maximum transmit range T_{max}.

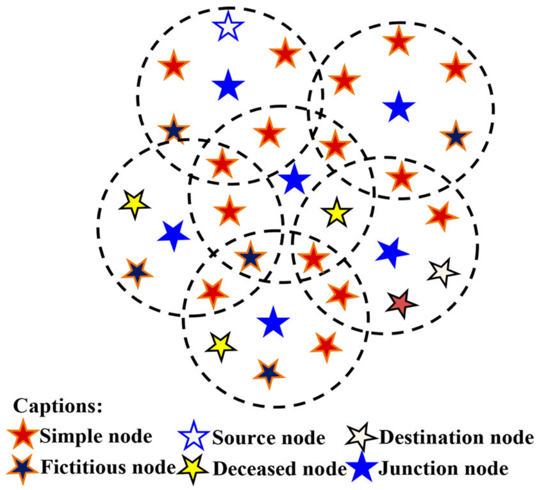

Fig. 5 Types of nodes

Nodes are prepared with a single Network Interface Card (NIC) and have a conveyance radius of r. Apart from these, it has at least one transmitter and one receiver. Any neighbor node N_i of node N_j is reside may or may not be within the range of node N_j due to dynamic nature of the network. This dynamic nature causes range variation of mobile nodes.

6.2.6 *Range variation of mobile nodes*

Range variation is the primary characteristic of mobile nodes due to their dynamic nature. At the time of packet travelling, when packets reach its destination node, it waits for a while. After that, it selects another arbitrary target point and replicates the same process frequently due to self-motivated nature of the network. Several types of nodes (e.g. simple node, source node, junction node, fictitious node, deceased node) are shown in Fig. 5 which participate in the communication. Each and every node may or may not be in range of a single node. There are several regions (Region-1, Region-2, Region-3, ., ., .,) available in the proposed network model. Nodes can send or receive data to or from its own range or from the range of other node. This range variation is shown in the Fig. 6. Figure 6(a) shows Region-1, where node N_1 and N_2 are source and destination node respectively. The dotted line indicates transmission between node N_1 and N_2. As same in Fig. 6(b), the communication between different regions as Region-2 and Region-3 using source and destination nodes N_3 and N_4 respectively. Figure 6(c) shows communication between different regions as Region-4 and Region-5 by containing multiple sources and destination nodes.

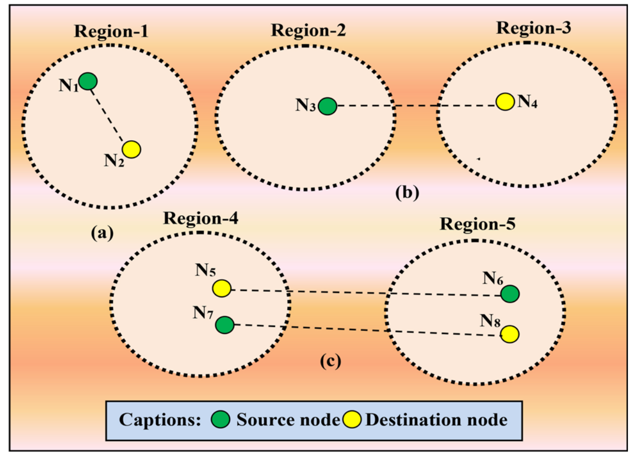

Fig. 6 Range variation of nodes

6.2.7 *Positional knowledge obtaining system*

The operational L_R X L_R region is a set of four points as C_1, C_2, C_3 and C_4. These points are denoted by a rectangle area (Λ) shown in Eq. 1 where all dynamic nodes are taking place randomly. The value of different points shown in Eqs. 2 to 5. The set of dynamic nodes ξ is shown in Eq. 6, where every mobile node $n_i \in$ V is familiar with its position given in the Eq. 7. So, at the time of measuring the distance of the node, we use the formula of the Euclidean distance [34, 35]. According to this formula, the distance (dist((x_i, y_i), (x_j, y_j))) between two points λ_1 and λ_2 in the plane with coordinates (x_i, y_i) and (x_j, y_j) is shown in Eq. 8. Both points λ_1 and λ_2 indicates the positions of nodes N_i and N_j. The procedure of considering positional knowledge of the node is shown in Fig. 7.

$$\Lambda = \{C_1 \cup C_2 \cup C_3 \cup C_4\} \tag{1}$$

$$C_1 = (x_1,\ y_1) \tag{2}$$

$$C_2 = (x_1,\ y_2) \tag{3}$$

$$C_3 = (x_2,\ y_2) \tag{4}$$

$$C_4 = (x_2,\ y_1) \tag{5}$$

$$\xi = \{N_1,\ N_2,\ N_3,\ N_4,\ N_5, \ldots N_n\} \tag{6}$$

$$pos(n_i) = (x\ (n_i), y\ (n_i)) \tag{7}$$

$$dist((x_i, y_i), (x_j, y_j)) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{8}$$

6.3 Route initiation

The IE2R is designed based on EN-AODV, so its nature is reactive. In this protocol, the route is designed when it required. When a source node wants to send data packet to

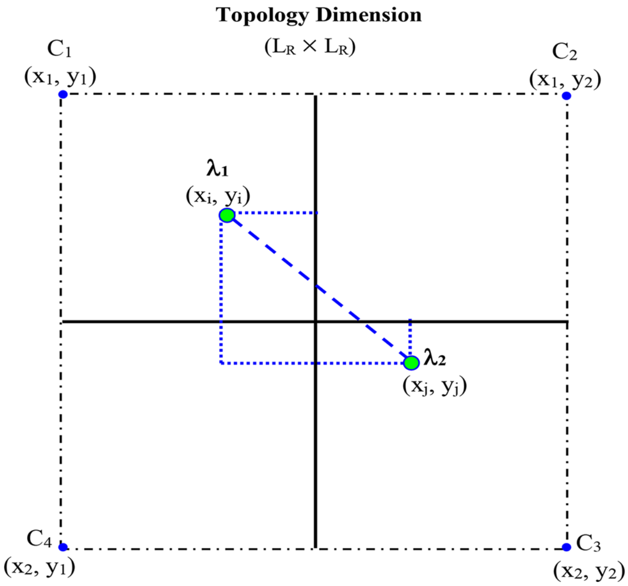

Fig. 7 Positional knowledge obtaining system

its destination node, it simply invokes the route discovery mechanism to find the path to the destination node. This process is completed when the source node finds all possible permutations of route. Once a route is discovered and established, it is preserve by route maintenance process.

6.4 Route discovery

In this phase, the route discovery algorithm is illustrated. It starts when the source node wishes to send data to its destination node. At this time, if route is available in "*R_table*" then it sends data otherwise it begins the route discovery process. This process starts with the helps of Route REQuest (RREQ) packet and HELLO packet. The packet format of the RREQ is shown in Fig. 8. It contains five fields such as Source IP address (*Src_add*), Source sequence number (*Src_seq#*), Broadcast id (*B_id*), Destination IP address (*Dst_add*), Destination sequence number (*Dst_seq#*). Each node keeps a Routing table (*R_table*) for storing routing information such as Destination IP address (Dest), Next hop node IP address (Next), Hop-count (Hop), Sequence number (*Seq#*), Junction flag (*J_FLAG*), Route list and different input parameters (Attributes of routes) of IE2R as I_1 (Hop-count), I_2 (Packet), I_3 (Residual energy), I_4 (Delay) and I_5 (Distance) which takes a part of MCDM. Figure 9 shows a complete information of "*R_table*". When a source node decides to send a data packet to its destination node first check in its "*R_table*". If route is available then it send data packet. At the time when node does not contain any information of the route; it will reserve the data packet, and generate HELLO messages which also has information about neighbor nodes. The purpose of this HELLO message is to initiate the route request process by spreading a RREQ packet to its neighbor. This strategy is known as downstream. The proposed protocol is loop-free, so it does not suffer from broadcasting storm [36]. The details of loop-freedom scheme is given below.

6.4.1 Loop-freedom scheme

The proposed protocol is based on EN-AODV protocol. In this protocol, each node maintained a monotonically incremental sequence number (*Seq#*) and loop-free routing. During route discovery, a node (N_i) may change its *Seq#* in its routing table (*R_table*) only in following three cases:

Case 1: If the current node is the destination node.
Case 2: If the current node receives a RREQ with a new sequence number.
Case 3: If the route towards to the destination node is failed.

At the time of sending the RREQ packet, decision maker checks residual energy (I_3) is greater than a certain threshold (Th) or not. If (I_3) is greater than "Th" then set *J_FLAG* as True and simultaneously it calculates input parameters I_1 to I_5 and update "*R_table*". If I_3 is lesser than "Th" then only update "*R_table*" and set *J_FLAG* as False. If I_3 is null (ϕ) then the decision maker ignore the node due to deceased. If "*R_table*" of any node is null (ϕ) then also ignore the node due to fictitious node. This downstream methodology of RREQ packet transmission is shown in Fig. 10. At the time of updating "*R_table*", upstream RREP also traced in the back direction. When RREQ reaches to the destination, then final RREP is generated and sends data packet via the highest ranking path. The entire route discovery operation covers with two tactics for three nodes (sender, receiver and intermediate) such as downstream and upstream shown in Fig. 11. The overall framework of route discovery is shown in Fig. 12.

Src_add	Src_seq#	B_id	Dst_add	Dst_seq#

Fig. 8 RREQ packet format

Dest	Next	Hop	Seq#	J_FLAG
Route list (R_1: n_{11}, n_{12}, , , , , , , , , , , n_{1q}) .. .. .. (R_p: n_{p1}, n_{p2}, , , , , , , , , , , n_{pq})			Attributes of route I_1 I_2 I_3 I_4 I_5	

Fig. 9 Structure of routing table

```
if (I3 >= Th)
then
    J_FLAG=True;    //the node is junction
    update R_table;
else if (I3 < Th)
then
    update R_table;    //the node is simple
else if (I3 ==ϕ)
then
    ignore ni;    //the node is decease
else if (R_table == ϕ)
then
    ignore ni;    //the node is fictitious
end if
```

Downstream methodology

Fig. 10 Downstream methodology for RREQ transmission

Sender Actions:

- **Downstream**
  Generate RREQ message.
  Broadcast RREQ.
- **Upstream**
  Receive RREP (include the path info).

Receiver Actions:

- **Downstream**
  Received RREQ.
  Generate RREP with path info.
- **Upstream**
  Broadcast RREP.

Intermediate node actions (downstream):

- Receive RREQ.
- Store upstream node info in R_table.
- Re-broadcast RREQ.

Intermediate node actions (downstream):

- Received RREP.
- If node is on the path then forward it.

Fig. 11 Types of actions during route discovery

6.5 Route maintenance

Route maintenance process is used to provide feedback related to node failure or link failure. It provides two advantages: to increase the stability of the network and to decrease the network overhead. In this phase, "*R_table*" is used as a routing table. During the routing process each and every node preserves and alters routing information in its "*R_table*" with the help of few control packets (e.g. RREQ, RREP, and RERR). If any node n_i fails in path P_i, it generates a RERR message to the node n_{i-1} and searches for a nearest Permanent Junction node (N_{PJn}). If any N_{PJn} is found, then it accepts a RERR message and sends RREQ to its frontage neighbor node. If any N_{PJn} is not found, then frontage neighbor node works as a Temporary Junction node (N_{TJn}) and the route is repaired. The pseudocode of the proposed route maintenance process is shown in Fig. 13.

6.6 Route selection

In this section, decision maker selects energy efficient route based on MCDM environment. There are several methods available in MCDM. Among those, two methods are used in the proposed route selection such as entropy and PROMETHEE-II. To select energy efficient route, decision maker use five parameters such as hop-count (I_1), packet (I_2), residual energy (I_3), delay (I_4) and distance (I_5). These parameters act as vague in practical applications instead of crisp. Due to this characteristic IFSS is used in MCDM environment. IFSS is a combination of IFS and soft set. IFS works with interval-based membership function which is more expressive in capturing vagueness of the data. It has the strong ability of describing uncertainties of the parameters. Soft set has the ability to deal with multi-parameters efficiently. IFSS has three interval-based Membership functions (MFs) such as true MFs (μ_A), false MFs (ν_A) and hesitation MFs (π_A). Decision maker evaluates energy efficient route in two steps: algorithm for determining weight to each parameter based on entropy weighting method, and algorithm for determining outranking to each route based on PROMETHEE-II aggregating method. Determining outranking to each route is based on weights of the parameters.

Let R be a preliminary universe set, E is a set of parameters, P_s (U) is the power set of U. Let I be a set of input parameters given by I = $(I_1 \cup I_2 \cup I_3 \cup I_4 \cup I_5) \subseteq$ E where I_1, I_2, I_3, I_4, I_5 are sets of different linguistic variable of IFSS. All pairs $(\hat{F}_1, I_1)$, $(\hat{F}_2, I_2)$, $(\hat{F}_3, I_3)$, $(\hat{F}_4, I_4)$ and $(\hat{F}_5, I_5)$ are an IFSS over R where $I_1 \subset$ I, $I_2 \subset$ I, $I_3 \subset$ I, $I_4 \subset$ I, $I_5 \subset$ I, $(I_1 \cup I_2 \cup I_3 \cup I_4 \cup I_5)$ = I, $\hat{F}_1$: $I_1 \rightarrow$ IFS (R), $\hat{F}_2$: $I_2 \rightarrow$ IFS (R), $\hat{F}_3$: $I_3 \rightarrow$ IFS (R), $\hat{F}_4$: $I_4 \rightarrow$ IFS (R), $\hat{F}_5$: $I_5 \rightarrow$ IFS (R), where IFS(R) indicates the group of all intuitionistic fuzzy sets on R.

For instance, let us consider R be a set of 'm' routes given by R = $\{R_1, R_2, R_3, , , , , , , R_m\}$ and it has five input parameters (i.e. I_1 to I_5). The MFs of each input parameter is given in Table 1. The universal set of input parameters is I = $I_1 \cup I_2 \cup I_3 \cup I_4 \cup I_5$. The different illustrating formulas for input parameters are shown in Eqs. 9 to 13.

$$I_1 = \sum_{k=1}^{l-1} H(n_k, n_{k+1}) \;\forall\; nodes\; n_k \in R_k \tag{9}$$

$$I_2 = \sum_{k=1}^{l-1} P(n_k, n_{k+1}) \;\forall\; nodes\; n_k \in R_k \tag{10}$$

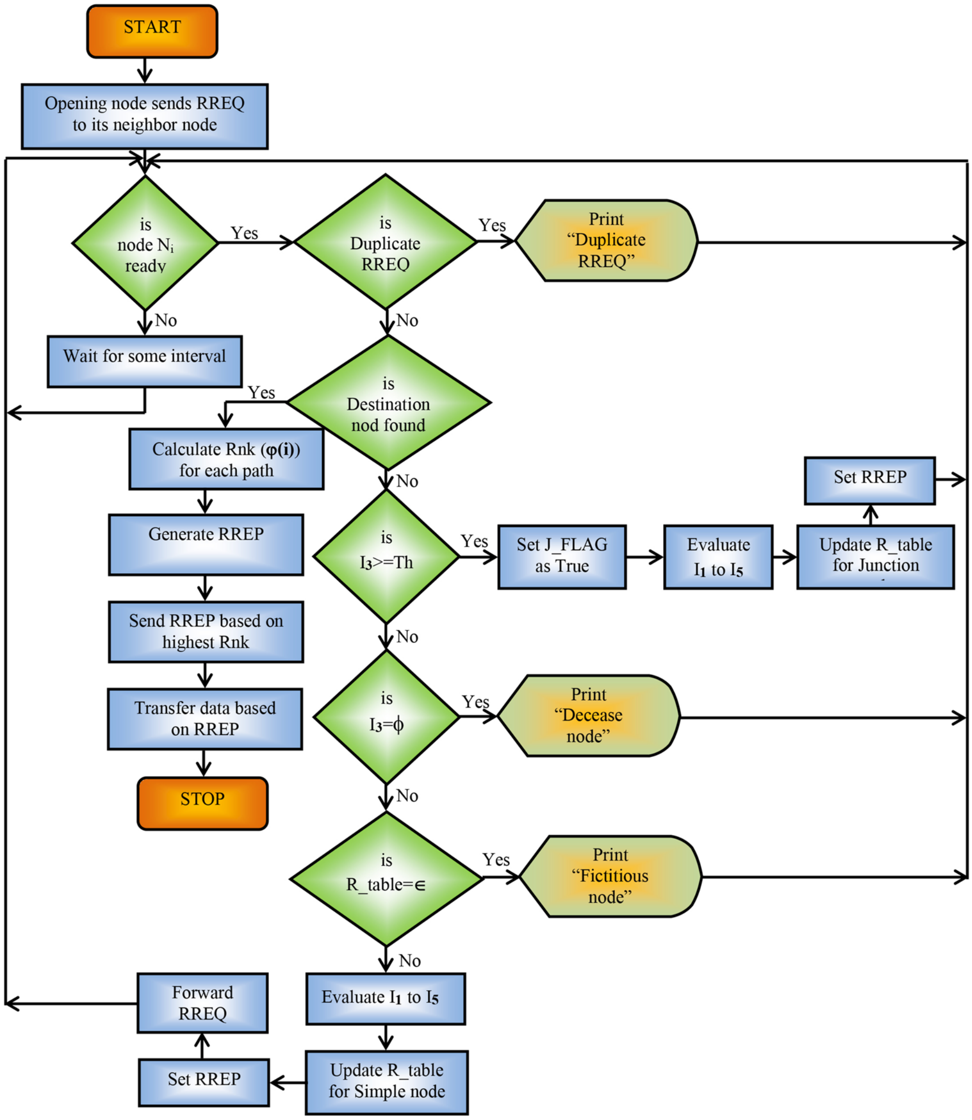

Fig. 12 The framework of route discovery

$$I_3 = \sum_{k=1}^{l-1} E(n_k, n_{k+1}) \; \forall \; nodes \; n_k \in R_k \tag{11}$$

$$I_4 = \sum_{k=1}^{l-1} D1(n_k, n_{k+1}) \; \forall \; nodes \; n_k \in R_k \tag{12}$$

$$I_5 = \sum_{k=1}^{l-1} D2(n_k, n_{k+1}) \; \forall \; nodes \; n_k \in R_k \tag{13}$$

where n_k to n_{k+1} are nodes in any route R_k while H denotes hop-count, P denotes packet, E denotes residual energy, D1 denotes delay and D2 denotes distance in transmitting and receiving a packet over one hop. In above equations, l-1 is the total number of nodes within a route R_k.

Now, different input parameters are arranged based on IFSS approach ($\hat{F_1}$, I_1), ($\hat{F_2}$, I_2), ($\hat{F_3}$, I_3), ($\hat{F_4}$, I_4) and ($\hat{F_5}$, I_5) can describe the possibilities of different linguistic variables of input parameters under intuitionistic fuzzy circumstances as shown in Eqs. 14 to 18. In these equations, t ∈ {1, 2, 3} and i ∈ {1, 2, 3, ..., m} for each t.

$$\hat{F}_{1\{I_1\}_{(h_t)}} = \frac{R_i}{\Delta Z} \tag{14}$$

$$\hat{F}_{1\{I_1\}_{(p_t)}} = \frac{R_i}{\Delta Z} \tag{15}$$

$$\hat{F}_{1\{I_1\}_{(e_t)}} = \frac{R_i}{\Delta Z} \tag{16}$$

$$\hat{F}_{1\{I_1\}_{(d1_t)}} = \frac{R_i}{\Delta Z} \tag{17}$$

$$\hat{F}_{1\{I_1\}_{(d2_t)}} = \frac{R_i}{\Delta Z} \tag{18}$$

The above IFSS for different parameters are defined for three linguistic variables for Low (i.e. t = 1), Medium (i.e. t = 2) and High (i.e. t = 3). In this approach, ΔZ is the maximum of

Algorithm for route maintenance

Input: (1) Set of nodes: $\xi = \{N_1, N_2, N_3, \ldots, N_n\}$.
(2) Set source node as S.
(3) Set permanent junction node as N_{PJn}.
(4) Set temporary junction node as N_{TJn}.
(5) Set initial energy as I_3.

Output: Repair path

```
Step 1: Start
Step 2: Assign flag=0, Tmp=0
Step 3: for each path do
    if (node Ni is failure) then
        generate RERR at node Ni-1
        i=i - ∇1 //move one hop back; ∇1 indicate one hop for same link
        Tmp=i //set current pointer at Tmp
            while (flag != 1 && Ni != S) do //search for nearest junction node from backside
                if (Ni == NPJn) then //if permanent junction node is found
                    flag=1
                    break
                endif
                i=i - ∇1 //move one hop back; ∇1 indicate one hop for same link
            endwhile
        if (flag == 1) then //if junction node is found
            receive RERR by node Ni
            i=i+∇2 //move one hop frontage; ∇2 indicate one hop for different link
            send RREQ via node Ni
        else if(flag==0) then //if permanent junction node is not found
            i=Tmp
            if (I3 of Ni != ϕ) then //check whether energy of node Ni is null or not
                set Ni as NTJn //set current node as temporary junction
                receive RERR by node ni
                i=i+∇2 //move one hop frontage; ∇2 indicate one hop for different link
                send RREQ via node Ni
            else
                source node re-discover the path
            endif
        endif
    endif
  endif
  endfor
Step 4: Stop
```

Fig. 13 Pseudocode of the proposed route maintenance method

the three membership functions such as true membership function (μ_A), false membership function (v_A) and hesitation membership function (π_A). Here, v_A membership function is rejected by the decision maker due to very less achievement. The illustrating formula for ΔZ is shown in Eq. 19.

$$\Delta Z = \begin{cases} 0, & \mathit{if}\ x = v_A \\ x, & \mathit{otherwise} \end{cases} \quad \mathit{where}\ x = \max(\mu_A, v_A, \pi_A) \tag{19}$$

Here, entropy method is used to calculate the objective importance of the indicator or input parameters as the weight of entropy. Hence, 'm' is considered as a set of routes and set of indicators (input parameters) is 5. The Evaluation matrix (E_{mat}) is formed with the helps of 'm' routes and '5' indicators as shown in Eq. 20. This matrix consists of evaluation of indicators for different routes where rows are tagged by different routes and columns are tagged by different indicators. Each cell (X_{ij}) is the value of evaluation of ith route for jth indicator calculated as $X_{11} = \mathrm{Mean}(\hat{F_1}_{\{I_1\}_{(h_1)}}, \hat{F_1}_{\{I_1\}_{(h_2)}}, \hat{F_1}_{\{I_1\}_{(h_3)}})$ for $\frac{R_i}{\Delta Z}$ where $i \in (1 \le i \le m)$ and so on.

$$E_{mat} = \begin{array}{c} \mathbf{R/I} \\ R_1 \\ R_2 \\ . \\ . \\ . \\ R_m \end{array} \begin{array}{c} \begin{array}{ccccc} I_1 & I_2 & I_3 & I_4 & I_5 \end{array} \\ \begin{pmatrix} X_{11} & X_{12} & X_{13} & X_{14} & X_{15} \\ X_{21} & X_{22} & X_{23} & X_{24} & X_{25} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ X_{m1} & X_{m2} & X_{m3} & X_{m4} & X_{m5} \end{pmatrix} \end{array} \tag{20}$$

(20)

Table 1 Membership function for input parameters

Input parameters	Membership functions		
Hop-count	Low	Medium	High
I_1	(h_1)	(h_2)	(h_3)
Packet	Low	Medium	High
I_2	(p_1)	(p_2)	(p_3)
Residual energy	Low	Medium	High
I_3	(e_1)	(e_2)	(e_3)
Delay	Low	Medium	High
I_4	$(d1_1)$	$(d1_2)$	$(d1_3)$
Distance	Low	Medium	High
I_5	$(d2_1)$	$(d2_2)$	$(d2_3)$

Algorithm for determining weight to each indicator:

Step 1: The elements of evaluation matrix are normalizing:

The matrix contains 'm' row with 5 indicators. The elements of this evaluation matrix are in the range between 0 and 1. Each and every element of this matrix are normalized by using Eq. 21.

$$\begin{cases} \frac{X_{ij}}{max\{x_{ij}\}j} : for\ max\ criterion \\ \frac{max\{x_{ij}\}j}{X_{ij}} : for\ min\ criterion \end{cases} \tag{21}$$

In Eq. 21, the maximum condition refers to all pointers with preferred superior rate. Therefore, each element is divided by the highest value of jth pointer (highest value in column 'j' in evaluation matrix). In other side, the minimum condition indicates the pointer with preferred lesser value and the lowest value is divided by each element. Based on this method, it is clear that $r_{ij} \in [0, 1]$.

Step 2: Evaluating the probability of the condition to arise is identified by p_{ij} as shown in Eq. 22.

$$p_{ij} = \frac{r_{ij}}{\sum_{j=1}^{m} r_{ij}} \tag{22}$$

Step 3: The entropy measurement of the jth criterion (indicator) is shown in Eq. 23.

$$E_j = -C \sum_{i=1}^{m} [p_{ij}.Ln(p_{ij})] \tag{23}$$

where C is a constant which is defined in Eq. 24.

$$C = \frac{1}{Ln(m)} \tag{24}$$

Step 4: Evaluating weight of entropy for the objective significance of the pointer: a weight allotted to a pointer is directly associated with the mean inherent fact produced by a given collected of data in addition to its subjective evaluation. This degree of deviation (D_j) of jth pointers are defined as the complementary of entropy value as shown in Eq. 25.

$$D_j = 1 - E_j \tag{25}$$

Hence, the objective of jth criteria is assessed as in Eq. 26.

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{26}$$

Equations 25 and 26 indicate that the pointers with less entropy values have a higher level of information content and thus a higher weight is assigned to them.

Algorithm for determining outranking to each route:

Step 1: The elements of evaluation matrix are normalized by the helps of Eq. 27.

$$R_{ij} = \frac{X_{ij} - min(X_{ij})}{max(X_{ij}) - min(X_{ij})} \tag{27}$$

where (i = 1, 2, ...m; j = 1, 2, ...5) and X_{ij} is the presentation degree in ith substitute based on jth condition. For non-favorable condition, Eq. 27 can be rewrite as given:

$$R_{ij} = \frac{max(X_{ij}) - X_{ij})}{max(X_{ij}) - min(X_{ij})} \tag{28}$$

Step 2: Evaluate the changes of i^{th} alternative based to other substitutes. It indicates the evaluation of dissimilar in condition values between dissimilar substitutes pairwise.

Step 3: Evaluate the predilection function, P_j(i,i′). Preference function is adopted by the decision maker shown in Eqs. 29 and 30.

$$P_j\ (i, i') = 0,\ if\ R_{ij} \leq Ri'j \tag{29}$$

$$P_j\ (i, i') = (R_{ij} - Ri'j),\ if\ R_{ij} \geq Ri'j \tag{30}$$

Step 4: Criteria weights are used to evaluate aggregate preference function shown in Eq. 31.

$$\pi(i, i') = \frac{\sum_{j-1}^{5} w_j * P_j(i, i')}{\sum_{j=1}^{5} w_j} \tag{31}$$

where w_j is the relative importance (weight) of jth criterion.

Step 5: Designing entering and leaving outranking flows. Leaving (or positive) flow for ith alternative is shown in Eq. 32.

$$\phi^+(i) = \frac{1}{m-1} \sum_{i'=1}^{m} \pi(i, i') \tag{32}$$

Entering (or negative) flow for ith alternative is shown in Eq. 33.

$$\phi^-(i) = \frac{1}{m-1} \sum_{i'=1}^{m} \pi(i, i') \tag{33}$$

In both Eqs. 32 and 33, 'm' is the number of routes.

Step 6: Evaluate the net outranking flow for each route based on Eq. 34.

$$\phi(i) = \phi^{+}(i) - \phi^{-}(i) \tag{34}$$

Step 7: Here, determine the outranking ($\phi(i)$) of all routes (R_1, R_2, $R_3, \ldots R_m$) based on the leaving flow ($\phi^{+}(i)$) and entering flow ($\phi^{-}(i)$). The highest value of $\phi(i)$ is the optimal energy efficient route for MANET.

7 Performance evaluation

In this section, performance evaluation of IE2R is evaluated using NS-2.35 simulator. It provides the details of the mechanism of how IE2R and other existing protocols (EN-AODV [16], RECI [17], and EASRP [19]) behave with respect to each and other. Several components of performance evaluation such as simulation model, simulation setup, and performance metrics are discussed below.

7.1 Simulation model

Simulation model is a simulation prototype of proposed protocol in the NS-2 simulator environment. The NS-2 simulator is an open source software which runs on Linux operating system. Simulation of the proposed protocol is performed by using some steps. The pictorial representation of these steps are shown in Fig. 14. To design the proposed protocol some modification is needed in the existing protocol (EN-AODV). Basically, C++ source files (i.e. .cc extension file) and C++ library files (i.e. .h extension file) of EN-AODV play backend role to design the proposed protocol. Object Tool Command Language (OTCL) is a script (i.e. .tcl extension file) which is used to draw a scenario of the proposed model. This script is driven by C++ source and library files. After execution of the script, it generates two output files such as trace file (i.e. .tr extension file) and nam file (i.e. .nam extension file). Trace file stores all tracing related data that gets generated during simulation. Nam file is used to illustrate the scenario of the protocol. After viewing and analyzing Network Animator (NAM), parsing of traced data with the help of awk file is done. This file is used to perform actions based on pattern matching. It scans input lines from trace file sequentially, and also examines and evaluates instruction based on decision maker. The basic aim of this file to evaluate several network metrics.

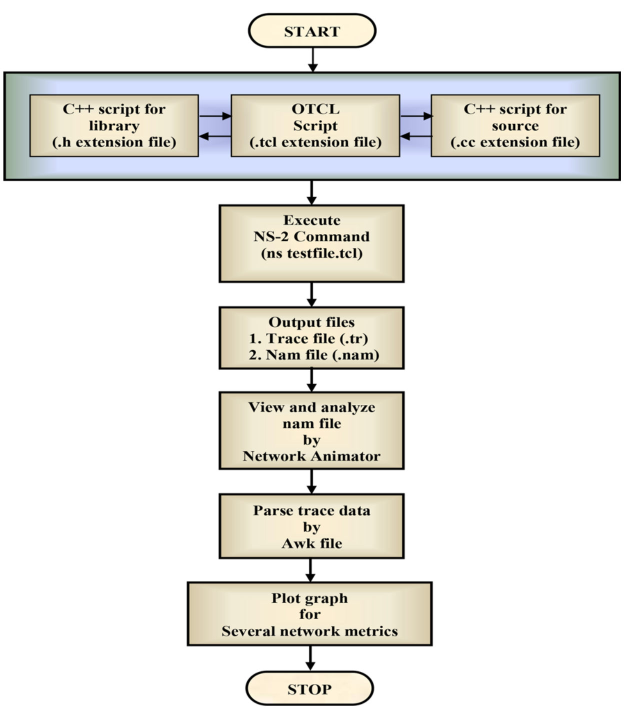

Fig. 14 Flowchart of simulation model

7.2 Simulation setup

Simulation setup of the proposed protocol is based on several network parameters. To simulate the proposed protocol maximum 100 nodes is considered that are arbitrarily organized in L_R X L_R operational region. The value of L_R is 1500 m. Initial energy given to all nodes is 50 joules including transmission energy as 5 joules and receiving energy as 5 joules. IEEE 802.11 is used as MAC layer protocol. Several traffic originators are designed to imitate constant bit rate sources. The details of simulation setup are given in Table 2.

7.3 Performance metrics

In a real environment, the signal reaches to the destination node via different paths. Hence, in proposed protocol, nodes are moved according to Random Way Point Mobility model (RWPM). The link reliability of nodes are modelled based on method described in [37]. It gives a precise estimation of the contradictory nature of the network. This estimation helps to prevent some disturbances such as interference, noise, wireless channel impairments etc.

The proposed protocol is reactive, source initiated and loop avoidant in nature. It has the approximate reasoning based capability due to combined features of IFSS with MCDM. It outperforms other considered protocols by significantly enhancing network metrics such as residual energy, network lifetime, packet delivery ratio, throughput, scalability, bandwidth and robustness. So, it has very good connectivity status than other protocols. Apart from these, its delay and packet loss are very low compared to other

Table 2 Simulation parameters

Simulation parameter	Value
NS-2 simulator version	NS 2.25
Topology size	1500 m × 1500 m
MAC layer type	IEEE 802.11
Network interface type	Phy/WirelessPhy
Maximum number of nodes	100
Protocols	IE2R, EASRP, RECI,
Under test	and EN-AODV
Simulation duration	1000 s
Initial energy	50 Joules
Transmission energy	5 Joules
Receiving energy	5 Joules
Mobility model	Random waypoint model
Traffic type	CBR (TCP)
Number of source	1
Number of destination	1

protocols. It handles high mobility traffic load, mutual interference and imprecise information among different nodes efficiently. Therefore, its QoS is better than other protocols. The summarized details of these characteristics is given in Table 3.

There are different objectives that are considered for route selection such as (1) maximize network lifetime; (2) maximize residual energy; (3) minimize average end-to-end delay; (4) maximize packet delivery ratio; (5) minimize communication or normalized routing overhead; (6) maximize throughput; (7) maximize energy goodput; (8) minimize jitter; and (9) minimize packet loss. Detail discussion of these objectives are given below.

7.3.1 Residual energy and network lifetime

Residual energy indicates the remaining energy of the nodes which is left over after the data transmission. Network lifetime indicates the time duration between which the network starts running and the time when half of the nodes run out of energy. It increases as we save energy in the individual nodes. Figures 15 and 16 shows residual energy and network lifetime of four protocols at dissimilar traffic loads severally. Both the network metrics are decreases with the increase of data rates. The outcomes in Fig. 15 specify that the residual energy of IE2R is better than other protocols. At the similar point of time, the outcomes in Fig. 16 show the network lifetime of IE2R is better than the others protocols. The reason behind this is that other protocols do not takes an energy parameter as a part of MCDM. It exchange data by employing default power mechanism. In other protocols, energy is heavily consumed with fewer nodes. Thus, resulting in less corresponding remaining energy and shortened network lifetime. Hence, IE2R consumes less energy due to outranking method for route selection. Finally, it concludes that IE2R save the network energy consumption and prolong the network lifetime.

7.3.2 Average end-to-end delay

Average End-to-End Delay (AE2D) is the average time taken by a data packet to reach at the destination. It includes all possible delays caused by buffering during route discovery latency and queuing at the interface queue. Its formula is given in Eq. 35. Figure 17 shows the average end-to-end delay of all protocols with varying data rate with increase in data rate or network load. It illustrates that IE2R provides an obvious lower end-to-end delay compared with other existing protocols. The reason is that IE2R uses smaller transmission energy to transmit data packets. Because of this, a route is also chosen by PROMETHEE-II outranking method, which can efficiently reduce the number of routes re-established. It reduced intrusion, collision, retransmission, queuing delay and transmission delay.

$$AE2D = \frac{\sum(arrive\ time - send\ time)}{\sum Number\ of\ connections} \tag{35}$$

7.3.3 Packet delivery ratio

Packet Delivery Ratio (PDR) is the ratio of actual delivered packets and total sent packets. It's formula is shown in Eq. 36. PDR of different protocols are shown in Fig. 18 in cases when the nodes are increased from 20 to 100. In each protocol, PDR is decreasing with the increase of the number of nodes. The outcome of Fig. 18 indicate that PDR of IE2R is higher than others protocols under the same conditions. The reasons for this significant improvement are that IE2R considered hop-count, packet, residual energy, delay and distance in route selection. Other existing protocols considered few parameters in route selection. The EN-AODV protocol only considered hop count in the route selection. So, it's performance was less than the other protocols. The EASRP and RECI perform better than the EN-AODV protocol because it takes link quality into account. However, the performance of these two protocols drops as the number of nodes increases. The reason behind it, when the number of nodes is more during transmission than probability of local conflict is more. The result of this is maximum energy consumption and degradation of PDR. The IE2R exploits energy control scheme using MCDM, and each node tries to send data packet at highest power level, this can reduce local conflict and improve PDR. Hence, IE2R increased the network PDR and reduced the network packet loss ratio.

Table 3 Comparison of proposed protocol with other protocols

Sl. no.	Characteristics	IE2R	EASRP [19]	RECI [17]	EN-AODV [16]
1.	Routing scheme	Reactive	Proactive/reactive	Reactive	Reactive
2.	Routing loop avoidance	Yes	Yes	Yes	Yes
3.	Source initiated	Yes	Yes	Yes	Yes
4.	Receiver initiated	No	No	No	No
5.	QoS support	Very good	Good	Moderate	Less moderate
6.	Residual energy	High	Medium	Low	Very low
7.	Network lifetime	Very high	High	Medium	Low
8.	Delay	Very low	Low	Medium	High
9.	Packet delivery ratio	Very high	High	Medium	Low
10.	Communication overhead	Very low	Low	Medium	High
11.	Throughput	Very high	High	Medium	Low
12.	Packet loss	Very Low	Low	Medium	High
13.	Scalability	Extreme	More	Moderate	Less
14.	Bandwidth	Very high	High	Medium	Low
15.	Robustness	Much more	More	Moderate	Less
16.	Connectivity status	Very good	Good	Medium	Bad
17.	Handling high mobility	Very good	Good	Medium	Bad
18.	Handling high traffic load	Very good	Good	Medium	Bad
19.	Handling mutual interference	Very good	Good	Medium	Bad
20.	Handling imprecise informations	Very good	Good	Medium	Bad

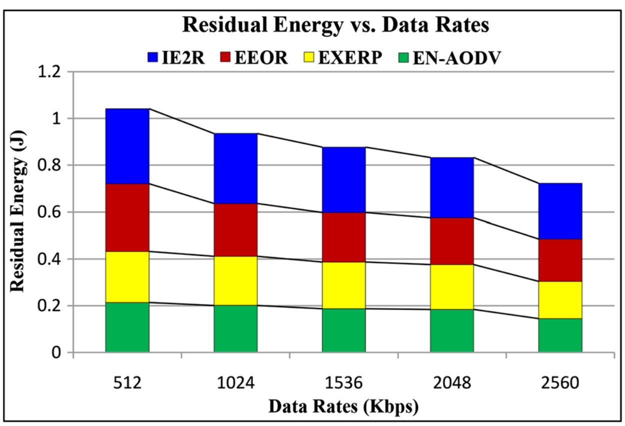

Fig. 15 Residual energy versus data rate

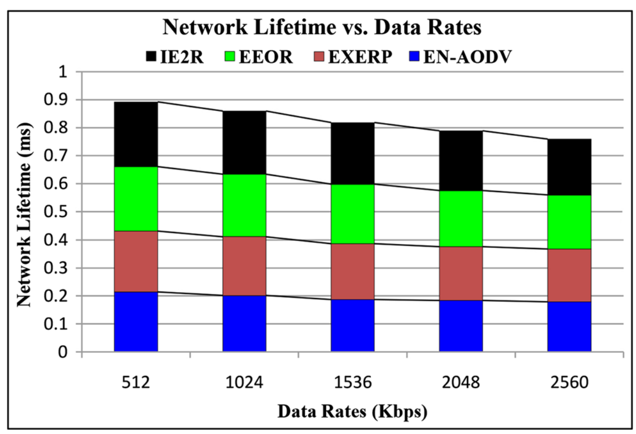

Fig. 16 Network lifetime versus data rate

$$PDR = \frac{\sum Number\ of\ received\ data\ by\ D.}{\sum Number\ of\ sent\ data\ by\ S} X100 \qquad (36)$$

where S is the source node and D is the destination node.

7.3.4 Communication overhead

Communication Overhead or Normalized Routing Overhead (CO/NRO) is defined to estimate how many transmission control packets are used for one successful data packet delivery. It determines the efficiency and scalability of the protocol. Its formula is shown in Eq. 37. Figure 19 shows the CO of four protocols with varying number of nodes. As the number of nodes increases, the CO also increases. CO of the IE2R is lower than other protocols. The IE2R protocol finds multiple paths in a single route discovery process using indicators of MCDM. So first weight is calculated to each route after that outranking is evaluated. Hence, each node tries to send data packets at a lower energy level, this can reduce local conflict. Another reason is that the IE2R restarts the route discovery process when all supporting paths have failed. Hence, IE2R

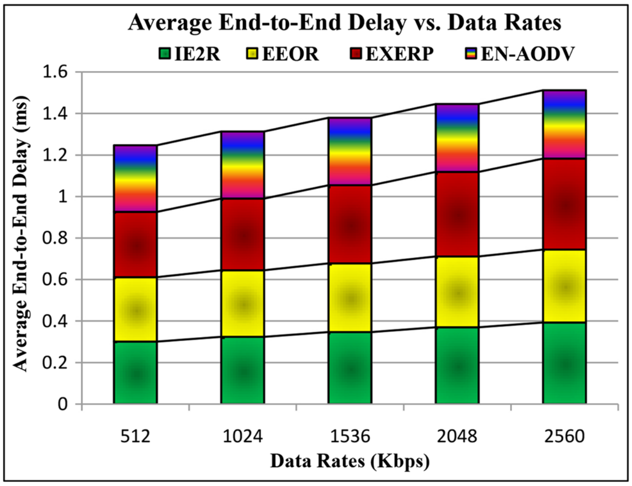

Fig. 17 Average end-to-end delay versus data rate

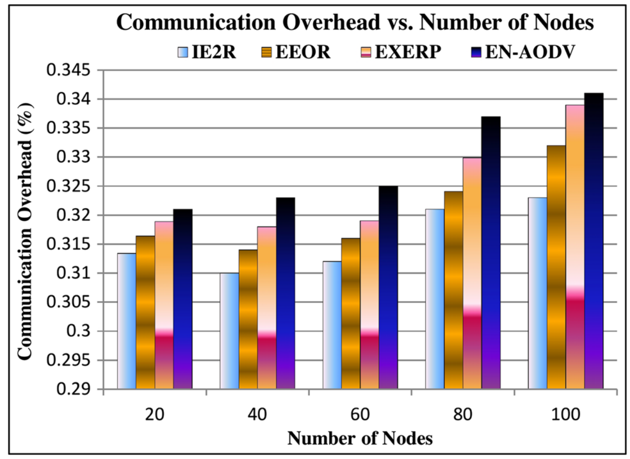

Fig. 19 Communication overhead versus number of nodes

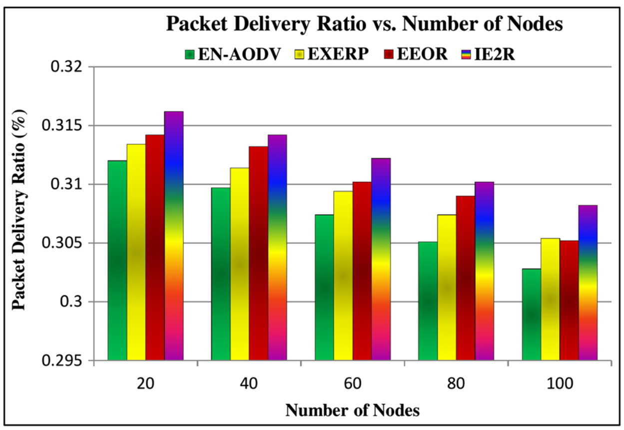

Fig. 18 Packet delivery ratio versus number of nodes

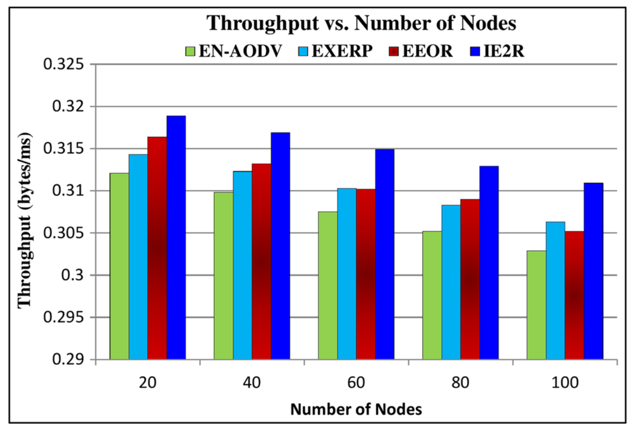

Fig. 20 Throughput versus number of nodes

reduced communication overhead as compared to the existing protocols.

$$CO = \frac{\sum Number\ of\ SentCtrlPkt\ by\ S}{\sum Number\ of\ received\ data\ by\ D} \quad (37)$$

where S is the source node and D is the destination node.

7.3.5 Throughput

Throughput is the amount of successfully received packets per unit time. It is measured in bytes per millisecond. Its formula is given in Eq. 38. Figure 20 shows an assessment between the proposed protocol and other existing protocols based on throughput and number of nodes. Throughput of four protocols are decreases as the number of nodes increases. It is well-known that throughput increases when connectivity is better. Hence, the throughput of the IE2R is higher than the other protocols. It is evident in the proposed routing protocol that the amount of successfully received packet is more than the other protocols. The reason being, IE2R selects efficient route using five parameters and routing decision is taken in MCDM environment. So, each node tries to send data packets at the best level indicator. It can reduce local conflict and improve the throughput. Hence, in IE2M the amount of successfully received packet is more than other protocols due to proper route selection technique.

$$Throughput = \frac{(DP * PS)}{T} \quad (38)$$

where DP is the number of delivered packet, and PS is the packet size and T is the total duration of the simulation.

7.3.6 Goodput

Goodput is the number of successfully received packets in a unit time and it represented in bytes per millisecond. It includes only useful data, but does not include undesirable data such as retransmissions, or overhead data. Figure 21 shows an assessment between the proposed protocol and other existing protocols based on goodput and number of

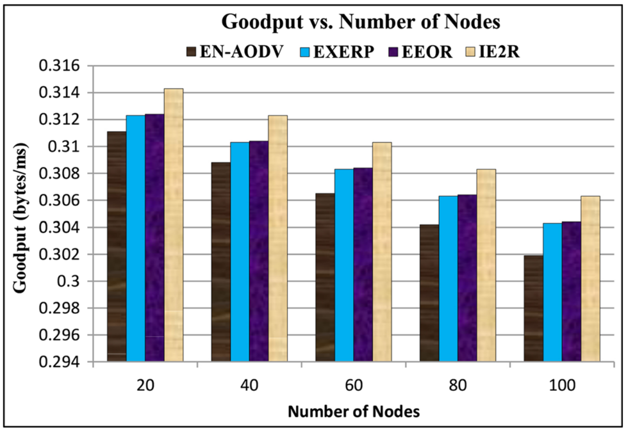

Fig. 21 Goodput versus number of nodes

nodes. It indicates that the goodput of the four protocols decreases with the increase in number of nodes. The goodput of IE2R is higher than the other protocols. The main reason for this is IFSS approach was used in a suitable way for efficient route selection using a decision making operator. The routing decision is taken by MCDM indicators. So, each node tries to send data packets based on outranking of route. It reduced local conflicts and improved the goodput. Therefore, in IE2M amount of successfully received actual packets is more than other protocols due to proper route selection and better maintenance procedure.

7.3.7 Jitter

Jitter is the delay between two consecutive packet delivery mechanism. This variation occurs in each received data packet. It is commonly used as an indicator of consistency and stability of a network. The variation in the packet arrival time should be minimum for better performance of the network. It is measured by the formula of Eq. 39. Figure 22 displays the jitter variation of the four protocols based on data rates. As data rate increases, jitter also increases. In Fig. 22, IE2R provided a lower jitter compared to other protocols. The reason is that IE2R always chooses the most stable route for transmission and finds an alternate route through the indicator of MCDM before the route crashes. The selection of alternative route can be achieved with the help of junction node. However, as the number of link increases, IE2R performs better than EASRP, RECI, and EN-AODV. Therefore, the IE2R enhanced the packet success ratio as compared to other routing protocols.

$$Jitter = \frac{\sum Delays_{packet_{delivered}}}{Packet_{application_{delivered}}} \tag{39}$$

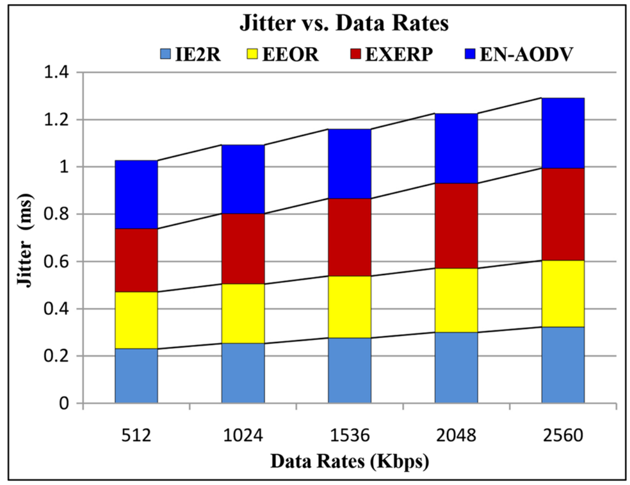

Fig. 22 Jitter versus data rates

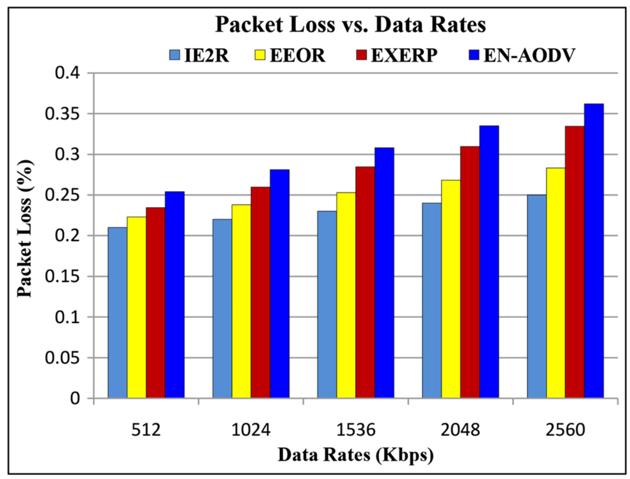

Fig. 23 Packet loss versus data rates

7.3.8 Packet loss

Figure 23 illustrates packet loss of four protocols. It indicates, IE2R has more reliable result compared to other protocols. It is measured by the formula of Eq. 40. It increased with the increases of data rates. The packet drop rate is much lower in IE2R as compared to other protocols. One of the main reason is that IE2R always chooses the most stable route for transmission and finds an alternate route through the indicator of MCDM before the route breaks. The selection of alternative route can be achieved with the help of junction node. Therefore, the proposed protocol enhances the packet success ratio as compared to other existing energy efficient routing protocols.

$$Packet\ Loss = \frac{Total\ Packets\ Dropped}{Total\ Data\ Packets\ Sent} X100 \tag{40}$$

7.4 Computational complexity

The IE2R is an integration of IFSS and MCDM techniques, where IFSS is a combination of IFS and soft set. IFS is an extension of fuzzy set. Fuzzy set works with point-based membership function, but IFS work with interval-based membership function which is more expressive in capturing vagueness of the data. It has strong ability of describing uncertainties of the network. Soft set theory has the ability to deal with multi-parameter efficiently. A combination of both provides a technique (i.e. IFSS) to model the recognition of uncertainty and imprecise knowledge efficiently. It deals with partial information during unpredictability situations of the network. Parameters of IFSS are discrete fuzzy variable which has strong ability to reduce the computational complexity of the decision process due to approximation nature. This characteristic gives optimal output by employing best combination of discrete input parameters. Hence, it has comparatively less computational complexity than other approaches as other approaches are based on crisp nature. Apart from this, computational complexity is dependent on three basic constraints such as additive, multiplicative and concave. The additive constraint indicates average end-to-end delay. The multiplicative constraint indicates the probability of a packet sent which is expressed in terms of packet loss. The concave constraint indicates bandwidth. In performance metrics evaluation, we have seen that the three constraints give optimum results. Therefore, the computational complexity of the proposed protocol is moderate.

7.5 The trade-off between packet delivery versus routing performance

Packet deliveries and routing performance both are reconciling in natures. So based on several performance metrics, the IE2R exploits the trade-off between packet deliveries and routing performance. Detailed illustration are given below:

Packet delivery ratio represents the maximum throughput that the network can achieve. A high packet delivery ratio indicates that routing performance is good. The packet delivery ratio is improved based on several QoS constraints [38]. These constraints are specified in terms of end-to-end performance such as probability of packet loss, end-to-end delay, bandwidth, jitter, etc. The QoS constraint could be three types such as additive, multiplicative, and concave. Mathematical model of these constraints are given below:

Let 'W' be the performance metric for the path P_j, where P_j defined in Eq. 41.

$$P_j = (N_s, N_1, N_2, \ldots, N_k, N_d) \tag{41}$$

Now, three type constraints defined as:

1. ***Additive constraint:*** A constraint is additive if it satisfied Eq. 42.

$$W(P_j) = \sum_{i=s}^{d} W(N_i, N_{i+1}) \tag{42}$$

For example, the end-to-end delay is an additive constraint because it consists of the summation of delay for each link in a path P_j.

2. ***Multiplicative constraint:*** A constraint is multiplicative if it satisfied Eq. 43.

$$W(P_j) = \prod_{i=s}^{d} W(N_i, N_{i+1}) \tag{43}$$

The probability of a packet sent from a node N_i to node N_{i+1} is multiplicative, because it is the product of the individual probabilities in a path P_j.

3. ***Concave constraint:*** A constraint is concave if it satisfied Eq. 44.

$$W(P_j) = \min(Ni, N_{i+1})_{i=s}^{d} \tag{44}$$

The bandwidth requirement for a path between node N_s and N_d is concave because it indicates minimum bandwidth among all link of a path P_j.

Apart from these, sometimes, a data packet at the end of the queues are dropped for several nodes. This time maximum throughput of nodes cannot be satisfied and packet delivery ratio reduces. Hence, overall routing performance degrades. Due to routing performance degradation there is increase of the data rate or traffic. Data queues at the nodes also increases and sometimes it becomes jammed.

8 Conclusions and future enhancements

In this paper, a novel Intelligent Energy-aware Efficient Routing protocol (IE2R) for MANET was presented. The aim of this paper is to design an energy efficient routing protocol in multi-constraints network, it is well known that decision makers face various problems due to vague and incomplete information in the network. The characteristics of these problems often necessitates this kind of information. In this protocol, IFSS and MCDM both were combined to achieve laid down purpose of IE2M. The combination approach helps to recognize imprecise information efficiently. It easily reduces uncertainties and vagueness of the network resources. It takes correct decision during the route selection, where multiple conflicted parameters are discrete variables. Therefore, it finds an overall good balance between parameters and performance of the network. It also decreases mathematical complexity as well as computational complexity. The simulation results illustrates the effectiveness of the IE2R compared to the existing protocols. The proposed work can be a suggestive approach for a real life application such as military search and rescue operations. The limitation of this protocol is that this protocol is reactive in nature, so until the flow is initiated, it will not discover a route. Therefore, route discovery latency is high for large networks. So our future work is to extend this work in heavy traffic conditions and to analyze the proposed protocol in mathematical approach and compare the analytical results with simulation results.

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