ROUTING PROTOCOLS IN INTERNET OF THINGS

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MASTER OF TECHNOLOGY

IN

COMPUTER SCIENCE AND TECHNOLOGY

BY

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This is to certify that the dissertation entitled **"ROUTING PROTOCOLS IN INTERNET OF THINGS"**, being submitted **by Mr. Kirshna Kumar** to the School of Computer and Systems Sciences, **Jawaharlal Nehru University**, New Delhi, India, in partial fulfillment of the require ments for the award of the degree of **Master of Technology** in **Computer Science and Technology**, is a record of bonafide work carried out by him under the supervision of **Dr. Sushil Kumar, Assistant Professor**.

The matter embodied in this dissertation has not been submitted to any other University or Institution for the award of any other degree or diploma.

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DECLARATION

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Dedicated to

My family and friend

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ABSTRACT

In communication networks, Internet of things (IoT) is going to become a prominent research area for government, citizens, industries, academia and hospitals due to its applications in healthcare, smart home, smart cities and environmental monitoring. In future communication networks with IoT, each of the things will be able to communicate with other things ubiquitously throughout the time clock. For using low cost and easily deployable smart devices, Wireless Sensor Network (WSNs) is very important to enhance ubiquity of network.

Multipath distortion, noise and interference create problems for low power communication devices. These smart devices contain limited amount of battery, energy and processing power. In IoT based application, energy efficiency and delay are key factors for network performance. In this context this dissertation proposes Routing protocol based on Energy, Link quality and Distance (RELD) to enhance routing success probability and to minimize route setup delay. It considers link quality and energy efficiency. For that purpose RELD technique finds optimized route on the basis of proposed end-to-end link quality estimation techniques, residual energy and distance.

Finally, the performance of the proposed algorithm is evaluated with respect to the protocol: REL considering the metric such as routing success probability and route setup delay in the various rounds. All these simulation works execute in MATLAB 2009b. The results demonstrate that the performance of proposed algorithm is better than the compared algorithm: REL in terms of routing success probability and route setup delay on the simulated network in IoT applications.

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CHAPTER 1

INTRODUCTION

1.1 Internet of Things

Internet of Things (IoT) is the process of creating, accumulating and communicating information among smart devices with or without human intervention. Things or Objects with communication capabilities and embedded intelligence are known as Smart Devices. Smart phones, healthcare gadgets, sensors, cars, RFID tags etc. are examples of such devices. In Internet communication occurs between users, while in IoT communication occurs between devices automatically [1].

Usage of IoT is increasing day by day. In 2003, 500 $million$ devices are connected to Internet, while population of world was 6.3 $billion$. By 2010 population was 6.8$billion$, while the number of devices connected to internet increased to 12.5 $billion$. By 2015 world's population will be about 7.2 $billion$, but the number of devices connected will be about 25 $billion$. By 2020 it is estimated that connected devices will be about 50 $billion$ which is 4 times of world's population. It shows the expansion of IoT in the world and dependability on IoT [2].

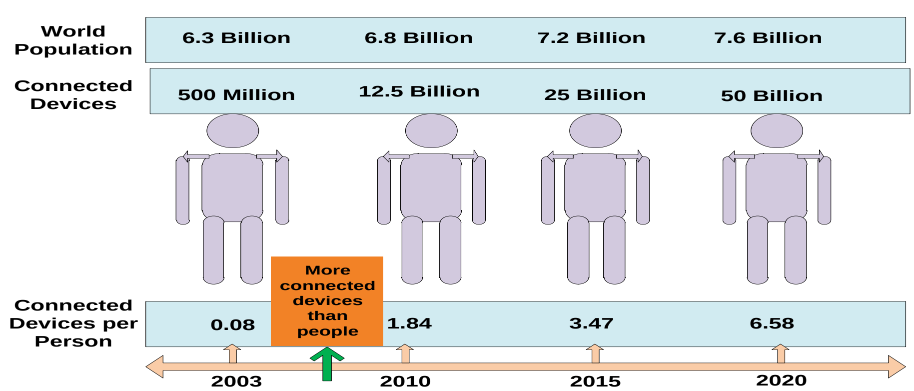

Figure 1.1 No of connected devices v/s world population

1.2. Components of IoT

For providing seamless ubiquitous computing, there are three components of IoT as discussed below.

- **Hardware**
  It contains various sensors, actuators and embedded communication hardware.

- **Middleware**
  It contains on demand storage and computing tools for data analysis.

- **Presentation**
  For accessing widely on different platform and designing for different applications visualization and interpretation tools are used [3].

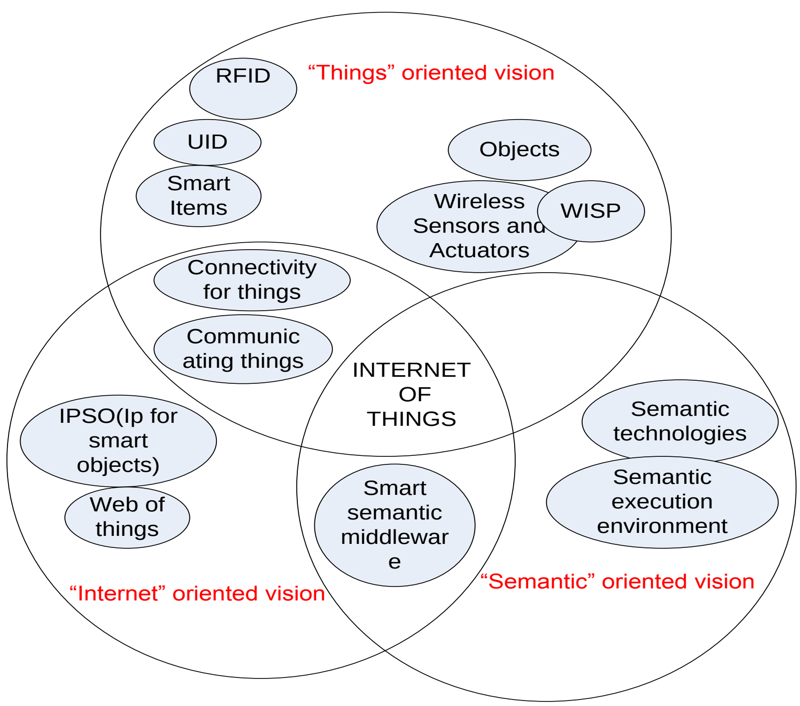

Figure 1.2 "Internet of Things" paradigms for different visions

1.3 Characteristics of IoT

There are various key characteristics of IoT. The Objective of each characteristic is network performance and network efficiency.

- **Intelligence**

  Smart product experience is made by intelligent spark with the help of computer (software and hardware) and algorithm. Nest's intelligent thermo state is compared with misfit shine, a fitness tracker. Computation works between a cloud and the smart phone is distributed by shine experience. For artificial intelligence, the nest thermo state provides more computation horsepower to make them smarter.

- **Connectivity**

  Connectivity plays more powerful role in IoT more than calling it a day and slapping on a Wi-Fi module. Network compatibility and accessibility is enabled by connectivity. Accessing on a network is accessibility. While the capability of consuming and producing data is called compatibility.

- **Expressing**

  Expressing is a way of interaction between real world and people. A mean of creating thing for intelligent interaction to physical world is provided by expressing for technically smart agricultural farm and smart home. Expressing provides permission for people to product into the physical environment and interaction between physical environment and people.

- **Safety**

  Safety cannot be forgotten to obtain novel experiences, efficiencies and various advantages. Safety is important for both sender and receiver. Safety should be provided for our physical thing and personal important data. To create scaling security paradigm is meaning of securing networks, endpoints and moving data across the network.

- **Energy**

  Energy is a prime factor for bringing creations in our life. Batteries are not the sufficient resource to run a large number of products. To handle all these type of things in intelligent ecosystem, energy harvesting, charging infrastructure power capabilities are required.

- **Sensing**

  Our physical environment and people are understood and sensed by the technique of sensing. Sensing is simply reflects as an analog input from our physical environment, but it can help us to understand this complex environment to rich extent.

1.4 Applications of IoT

- **Home**

  IoT provides better energy, water and other home resources management inside home and at personal level. Use of home equipment such as refrigerator, washing machine, air conditioner etc. in controlled way is necessary for reducing electricity, water and other resource consumption. So that reduction in operational expenditure at economic level and control in pollution by reducing emission of various pollutants at social level.

- **City**

  The citizen’s life can be better and usage of physical city infrastructure can be improved utilizing the services of IoT. IoT can improve traffic control system, parking system, usage of power grid and road networks and forensic management. In traffic control system, car is taken as a smart object and sensors are used to get information like average speed and numbers of cars on the highways and to monitor flow of vehicular traffic.

- **Health**

  IoT provides various applications in medical field. Sensors attached to patient's body monitor various health parameters such as breathing activity, body temperature, pulse rate ,calories consumed by body etc. and these information is forwarded health centers. Wearable sensors with various applications running on computing devices enable person to analyze daily activities like exercises done, calories consumed etc. so that they can improve their lifestyle and control health diseases [3].

- **Forest fire detection**

  Once the possible presence of fire is detected by sensors, an indication is sent to corresponding department immediately using enhanced technology of IoT along with the information about the presence of number of persons and inflammable materials.

- **Air pollution monitoring**

  IoT services have been deployed in several cities to monitor the concentration of dangerous gases for the safety of citizens. Sensors detect the several pollution elements and their level in air and water and provide that information in health agencies.

- **Inventory and product management**

  In IoT, the movement of products is monitored and managed using RFID tags. RFID tags are attached to the products or to containers of these products. IoT presents advanced capabilities in terms of receiver's positions while it enables interoperability among RFID-based applications used by various users working with item throughout different stages of its lifecycle. Production process, resulted item quality and possible life reduction of the item can be controlled by using combination of bio-sensors with RFID technology.

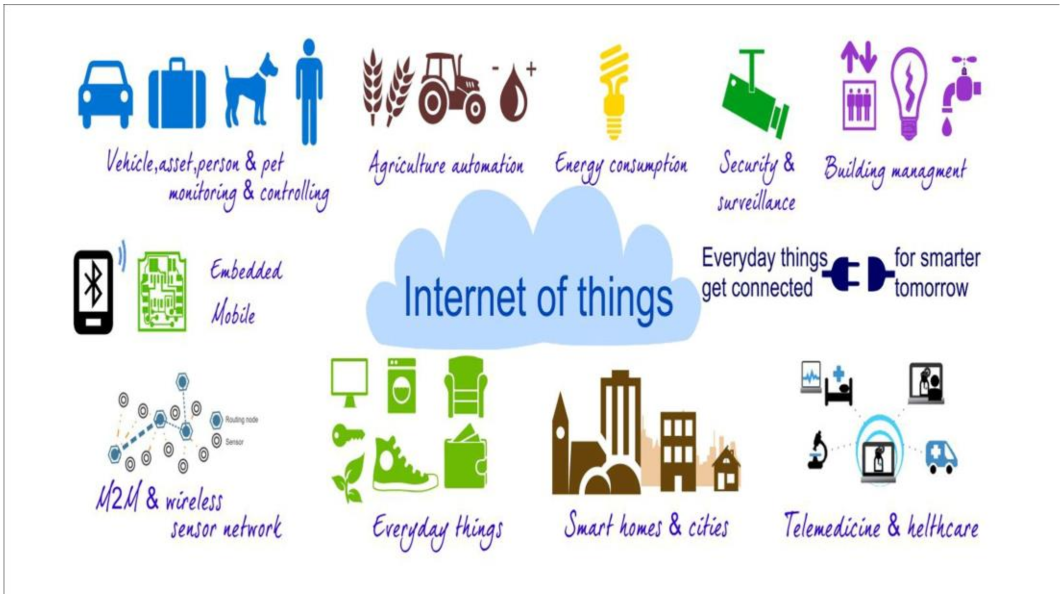

Figure 1.3 Applications of "Internet of Things" [4]

- **Security and Surveillance**

  The presence of dangerous chemicals and people with suspicious behavior can be monitored using RFID, ambient sensors and other sensors. Better user cooperation through diminution of the use of cameras, minimized operational cost and enhanced flexibility in a varying environment are the advantages of IoT functionalities [5].

1.5 Research Challenges in IoT

- **Heterogeneity of devices**

  Devices those communicate with each other contain different functionalities, computational capabilities and applications.

- **Scalability**

  The sensor nodes are deployed in respective area in the order of hundreds, thousands or more and events should be managed in scalable manner by routing techniques [6].

- **Devices limitations**

  Most of the devices used in IoT are limited for batteries life, processing power and memory. So energy harvesting technique is used to improve energy limitation of devices.

- **Self-configuration and self-organization capability**

  To minimize human intervention, devices should be able to react autonomously in different situations. So that devices can handle interference management and end to end communication [7].

- **Security**

  For adopting IoT technologies and applications at wider level, security is considered as a main component. It contains data confidentiality, privacy, authentication and integrity. Data confidentiality means that data accessing and data modification can be done by only authorized users and objects. Privacy defines the rules under which users can accessed the data.

- **Quality of Service (QoS)**

  The quality of service in IoT consists of various parameters, such as network lifetime, data reliability, energy efficiency, location - awareness and bandwidth utilization. Delivery of Data should be done within a certain period of time from sensing moment in different applications.

- **Cloud computing**

  To make IoT applications more effective and wider, cloud computing provides dynamic way of gathering and storing data. It offers different services such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (Saas).

- **New protocols**

  In IoT protocols play important role in complete realization. They work as a medium between sensors and physical world for data intelligence. There are various existing Mac protocols such as TDMA (collision free), CSMA (low traffic efficiency) and FDMA (collision free etc. and routing protocols such as AODV etc. but they are not so efficient for bandwidth utilization, energy optimization, delay minimization while using in IoT ecosystem [8].

- **Digital forgetting**

  All the information gathered about a person by the IoT may be detained indefinitely as the cost of storage reduces. Also data mining techniques can be used to easily getting any information even after various years.

- **Data mining**

  Obtaining important information at various spatial and temporal resolutions from a complicated sensing environment is a challenging research issue in artificial intelligence. There are various supervised and unsupervised learning techniques to obtain the information.

- **GIS based visualization**

  New visualization techniques to represent heterogeneous sensors in a 3D landscape have to be developed which is differed temporally. One other issue of visualizing collected data within IoT is that they are geo-related and are sparsely circulated. To endure with such an issue, an Internet GIS based framework is needed [9].

1.6 Routing Protocols

Routing protocols in Wireless Sensor Network have been a rising research topic for years and the research area has witnessed many achievements. In this report, we first show some examples of routing protocols for Wireless Sensor Network. The report also includes some routing protocols in Internet of Things.

1.6.1 Routing Protocols in WSNs

On the basis of different criteria routing protocols in Wireless Sensor Networks can be classified in different ways. In this part, routing protocols are divided into two criteria: Protocol Operations and network structure.

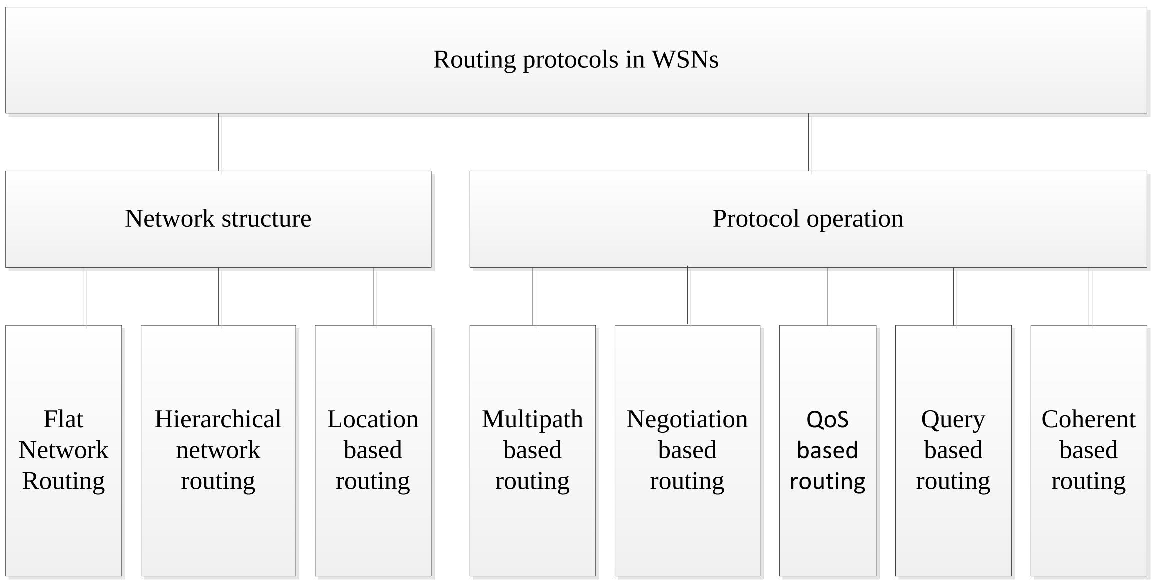

Figure 1.4 Routing protocols in WSNS

1.6.1.1 Routing protocols based on network structure

- **Flat network routing**

  In flat network routing, all nodes are homogenous. In the networks task sensation is performed by all nodes together. Because WSNs consist of a lots of such sensor nodes, so assigning of global node to every node is not feasible. So data centric (DC) routing comes into consideration. In DC, Base Station (BS) sends queries to pre-defined regions and waits for data from the sensor nodes that are located in given regions. Data centric routing and flooding are prime algorithms in flat routing. In flooding every node transmit data to all its neighbors and due to this, much redundancy of data takes place. In DC routing there are no global identifiers of given nodes. The attribute based naming is used to identify data. There are some protocols based on flat network routing. Minimum Cost Forwarding Algorithm (MCFA), Sensor Protocols for Information via Negotiation (SPIN), Gradient Based Routing (GBR).

- **Hierarchical routing**

  In WSNs, hierarchical architecture adopts the concept of clustering [10]. It reduces the communication overhead. In this routing, sensor nodes are grouped into clusters and each cluster contains a cluster head (CH). Some sensor nodes are responsible for sensing a target and some nodes are responsible for transmitting data to the BS. The CH can also perform data aggregation to reduce the amount of data before transmitting it, to the BS. In hierarchical routing, information is processed and sent by higher energy nodes, while task sensation is performed by low-energy nodes. There are some protocols based on hierarchical routing.

  Low-energy adaptive clustering hierarchy (LEACH), Minimum energy communication network (MECN), Power-Efficient Gathering in Sensor Information Systems (PEGASIS), Threshold-Sensitive Energy Efficient Sensor Network Protocols (TEEN).

- **Location based routing**

  This type of routing is based on the location of nodes. The incoming signal strengths are used to estimate the distance between neighboring hops. GPS is used to locate the nodes if nodes are equipped with a small low-power GPS receiver [12]. In location based routing each node knows its own location, its neighbor location and location of the destination node.

1.6.1.2 Routing protocols based on protocol operation

- **Multipath Routing protocols**

  In this kind of routing protocols, it uses multiple paths to optimize network performance [13]. If one path is not available it selects other possible path to transmit the packets.

- **Negotiation-Based Routing**

  Flooding produces implosion and overlap [14] between the sent data, due to this reason a node will receive duplicate copies of the same data. The sending of the same data from different nodes consumes more energy and processing. These types of protocols remove redundancy in data transmissions through negotiation.

- **QoS-Based Routing**

  These kinds of routing protocols are based on the quality of services. In QoS-based routing protocols [11], Quality of data and amount of energy consumed should be balanced when data deliver to the BS, the network has to satisfy various QoS metrics such as energy, delay and bandwidth.

- **Query-Based Routing**

  These kinds of routing protocols are based on the queries. The destination node propagates a query for data in the network, and a node that matches the query, transmits the data back to the hop that initiated the query.

- **Coherent and Non-coherent Processing**

  In WSNs, sensor nodes cooperate with each other to process the heterogeneous data. In coherent data processing routing, the data is forwarded to aggregators after minimum processing. The minimum processing includes tasks like duplicate suppression and time stamping [11]. In non-coherent data processing routing, nodes will locally process the raw data before it is sent to other nodes for further processing. Here aggregators are nodes those perform further processing.

1.6.2 Routing Protocols in IoT

In IoT, Routing protocols provide the mechanisms to select the path for data transmission from source node to destination node based on residual energy, end-to-end link quality and distribution of network resources. Some routing protocols currently used in IoT are described below.

- **IPv6 over Low Power Wireless Personal Area Network (6LoWPAN)**

  IPv6 over 802.15.4 is meant extend IPv6 to networks to IoT networks. The advantage of this approach is the possibility of re-using existing IPv6 technologies in infrastructures. However, this type of network is originally designed for computing devices with higher processing capability and memory resources which is not suitable for IoT network entities. IPv6 is also in use on the smart grid enabling smart meters and other devices to build a micro mesh network before sending the data back to the billing system using the IPv6 backbone. Some of these networks run over IEEE 802.15.4 radios, and therefore use the header compression and fragmentation as specified by RFC6282.

- **IPv6 Routing protocols for Low Power and Lossy Network (RPL)**

  IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL), which provides a technique whereby multipoint-to-point traffic from devices inside the LLN towards a central control point as well as point-to-multipoint traffic from the central control point to the devices inside the LLN are supported support for point-to-point traffic is also available.

  This protocol types are designed for network comprising of constraint devices in power, computation capability and memory. Thus the data transmission in this type of network is unreliable and has low data rate but high loss rate [14].

- **Constrained Application Protocol (CoAP)**

  CoAP is an application layer protocol that is intended for use in resource-constrained internet devices, such as WSN nodes. The most prominent feature in this type of routing protocols is the ability of translating to HTTP message so as to integrate with web services. The protocol also support multicast with little overhead. The Internet of Things will need billions of nodes, many of which will need to be inexpensive. CoAP has been designed to work on microcontrollers with as low as 10 KB of RAM and 100 KB of code space. CoAP resource directory provides a way to discover the properties of the nodes on the network.

- **Adhoc On Demand Vector Protocol (AODV)**

  In AODV, minimal number of hops is the basis of root selection process. Routes are discovered on demand.

  Merits- Well defined structure, low complexity and low overhead because of on-demand routes.

  Demerits- Failure of single route increases delay and failure rate of data delivery. More packet loss due to short route, lacking of energy efficiency mechanism and reliable data transmission which results in energy holes [15].

- **Link Quality-Based Lexical Routing (LABILE)**

  For evaluation of link quality and lexical structure, LABILE protocol is proposed. On the basis of Link quality index (LQI) values that are good or bad, end-to-end link quality is evaluated. LQI values are evaluated based on threshold.

  Merits- It provides good end-to-end link quality

  Demerits- Lacking of energy efficiency and load balancing mechanisms. Also results premature death of nodes [16].

- **Energy Efficient Unicast Routing Protocol (EEURP)**

  Route selection process is based on hope count, minimum energy level and end-to-end average energy consumption. Here minimum energy of path is described as a hop with critical level of energy.

  Merits- It provides good energy efficiency mechanism and focused on network life time.

  Demerits- Lacking of link quality estimation mechanism and does not provide QoS support for IoT applications [17].

CHAPTER 2

RELATED WORK

2.1 Greedy Packet Forwarding Scheme

Greedy routing algorithms provide the forwarding methods on the basis of location of the current forwarding node, its neighbors, and the packet destination. Based on this information each node takes decision to forward the data. This greedy principle is applied by every intermediate node [18] until the packets reaches to the destination node. Greedy routing can be based on progress, distance and direction.

2.1.1 Progress based

In the progress based scheme [18], the next forwarding node is selected based on the progress. Given a transmitting node S, the progress of a node A is defined as, the distance between a node S and the projection A' of a neighbor node A onto the line connecting S and destination D.

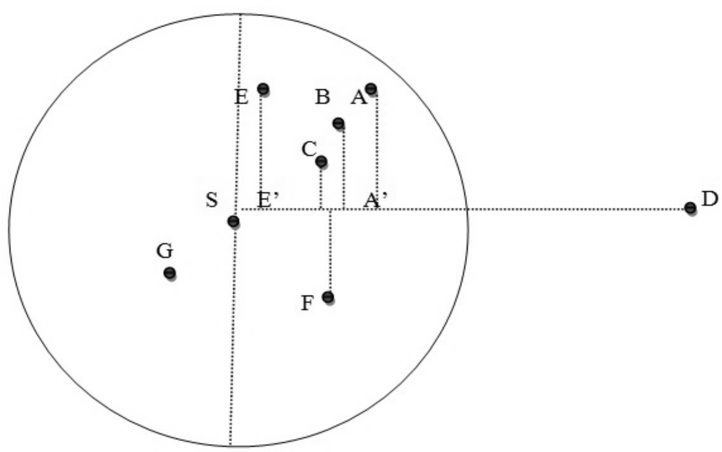

Figure 2.1 Progress based [18]

Neighbors with positive progress are said to be in forward direction. For example in **Figure** 2.1, the neighbors A, B, C, E and F are in forward direction. The remaining node G is in backward direction

2.1.2 Distance based

This distance based [17] greedy routing scheme is based on the distance. This scheme considers the Euclidean distance among all neighbors of sender S and the destination D. To forward the packets, forwarding node is selected based on the distance.

2.1.3 Direction-based

This greedy routing is based on direction. It considers the deviation (angle between current, next hop and destination node) from the line connecting active sender and destination [17]. Based on the direction, this current node selects next node to forward the packets.

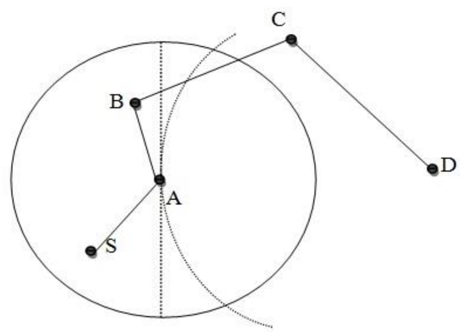

Figure 2.2 Local minimum problem [21]

A packet addressed to node D will be dropped at node A, because each neighbor of A (node S and node B) is in backward direction.

These greedy routing schemes cannot guarantee packet delivery even if there exists a route from source node to destination node. For example in **Figure** 2.2, there exists a route from source node S to destination node D. But a packet forwarded to node D is dropped at node A, because every neighbor node that is in its transmission range is in backward direction of this node. This type of situation is known as local minimum. Concave node is a node where greedy forwarding is paused [18].

Based on the notion of progress, Takagi and Klein rock [19] proposed the first position-based routing scheme.

2.1.4 Most forward within radius

Takagi and Klein rock [19] introduced the first position-based routing algorithm, called most forward within radius (MFR). Based on this scheme, a packet with destination D is forwarded in the forward direction. The neighbor with the maximum progress on the straight line is selected as next hop for sending packets [120]. In **Figure** 2.1, node S has neighbor node A with most forward progress.

2.1.5 Nearest with forward progress

Hou and Li [21] proposed nearest with forward progress (NFP) routing algorithm. In this algorithm each node transmits the packet to the nearest neighbor with forward progress. In **Figure** 2.1, node E is selected.

2.2 Routing Protocols Based on Position

2.2.1 Compass routing

Kranakis defined compass routing (DIR) [22], in which source or intermediate hop selects the neighbor that is closest to the straight line between sender and destination node. For example in **Figure** 2.3, node C is in the closest direction respective the line connecting sender node S and destination node D.

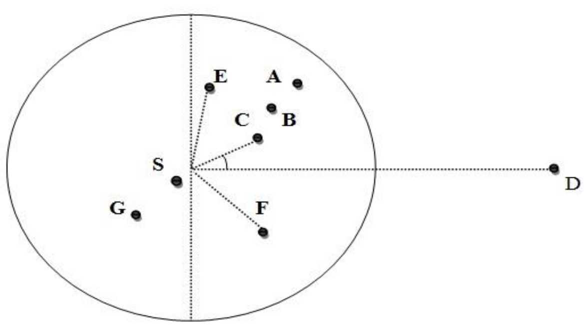

Figure 2.3 Compass routing [22]

In DIR method, when a packet is forwarded to the neighbor with closest direction may create a loop [23], as shown in **Figure** 2.4. The loop consists of four nodes, denoted E, F, G and H. Let the source node is E and the destination node is D. Node E selects node F to forward the packet, because the direction of F is closer to destination D than the direction of its other neighbor node H. Similarly node F selects G, node G selects node H and node H selects node E. In this Figure, a loop EFGHE is created. So, it is clear that DIR is not loop free.

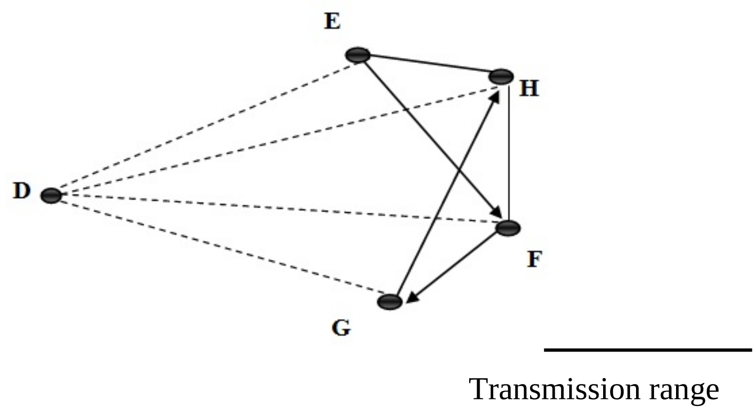

Figure 2.4 A loop in the directional routing [23]

2.2.2 Geographic distance routing (GEDIR)

GEDIR [24] is a position based greedy forwarding algorithm. It deals with the situations when the sending node itself is a local minimum (dead-end). A dead end problem occurs when a node which is nearest to the destination node in comparison to all its neighbors and not within the transmission range of the destination. For example, in **Figure** 2.5, assume node F wants to send a message to destination node D, but F and D are not within the transmission range of one another. In this case F is a dead-end but according to GEDIR scheme, node F will still forward message to node B, hoping that B may have another neighbor which is closest to the destination D.

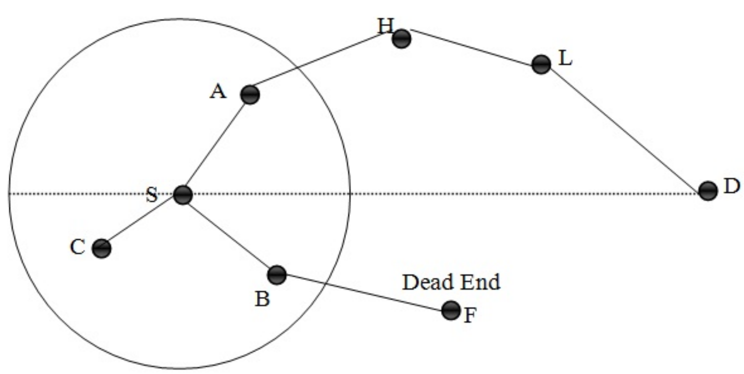

Figure 2.5 GEDIR routing [23]

2.3 Energy Efficient Probabilistic Routing protocol (EEPR)

This protocol propose energy-efficient probabilistic routing (EEPR) algorithm [25], which controls the transmission of the routing request packets stochastically in order to increase the network lifetime and decrease the packet loss under the flooding algorithm.

The proposed EEPR algorithm adopts energy-efficient probabilistic control by simultaneously using the residual energy of each node and ETX (Expected Transmission Count) metric in the context of the typical AODV (Adhoc On Demand Vector Protocol) protocol.

2.3.1 Basic EEPR

The proposed EEPR algorithm controls the request packet forwarding process in order to decrease the network congestion and the packet loss.

- By using the ETX metric, the EEPR algorithm composes the routing path with good link quality. Using the residual energy of each node as a routing metric makes it possible for all the nodes in the network to use their residual energy more evenly [24].
- We induce the ETX value metric not by using the heuristic method but by using the bit error rate (BER) based on the path-loss model.
- The received signal strength (RSS), the signal strength that the receiving node senses, is calculated as

$$RSS_{dB}(x) = P_{dBm}^{tx} - P_{dB}^{loss}(x) \quad (1)$$

- Where $RSS_{dB}(x)$, P_{dBm}^{tx}, and $P_{dB}^{loss}(x)$ are RSS at a node which is away x km from the source node (dB scale), transmission power of the source node (dBm scale), and path loss at x km from the source node (dB scale), respectively. Then, signal-to-noise ratio (SNR) is calculated as

$$SNR(x) = \frac{2 \times RSS_W(x)}{P_W^{noise}} \quad (2)$$

- Where SNR(x), $RSS_W(x)$ and P_W^{noise} are SNR value at a node which is away x km from the source node, RSS at a node which is away x km from the source node (Watt scale), and noise power (Watt scale), respectively. By using the above SNR value, the BER is calculated with the assumption of the ITU Pedestrian A model [23].

- Then the desired packet error rate (PER) is obtained as

$$E_{pp=1-(1-E_b)^{L_{pp}}} \quad (3)$$

- Where E_{pp}, E_b, and L_{pp} are PER of a probe packet, BER, and the size of a probe packet, respectively. We calculate the ETX of each link by counting the number of probe packets that a node receives when the total number of probe packets is 10.
- The result of the ETX metric via distance is shown in Figure 1.
- The second routing matrices used are Residual energy which results evenly use of residual energy of all the nodes. Here E_i and E_{max} are residual energy and maximum residual energy of node I respectively.
- Then, the forwarding probability p of node under the proposed EEPR algorithm is determined by

$$p = [P_{min} + E_i A[1 + \frac{(E_{(i-1,i)} - ETX_{max})}{(1 - ETX_{max})}]]^{1/\propto} \quad (4)$$

Where $A = \frac{1 - P_{min}}{2 \times E_{max}}$

- Where P_{min} and $\propto$ are predefined minimum forwarding probability and the weighted factor for variation of the forwarding probability respectively.
- When a node has high residual energy and the link has low ETX value, the forwarding probability is high. Even when a link has far lower ETX value because of good link quality, when the amount of residual energy of a node is small, the forwarding probability is low.
- According to (4), a node with lower residual energy has lower forwarding probability. However, when all nodes in the network have low residual energy, most of forwarder nodes discard the RREQ packets because of low forwarding probability. In this case, routing process can be failed continuously.

2.3.2 Advanced EEPR

To overcome above failure advanced EEPR algorithm is proposed. To describe the advanced EEPR algorithm, we should assume two factors. First, it is each node knows the average value which is calculated by the network controller using the periodically received information about the residual energy from every node.

Second, every node usually has knowledge of residual energy of its one-hop distance nodes from the hello packets which are of residual that assumed energy of each node inside the network, periodically broadcasted by each node in order to indicate the existence and some information of the node [26].

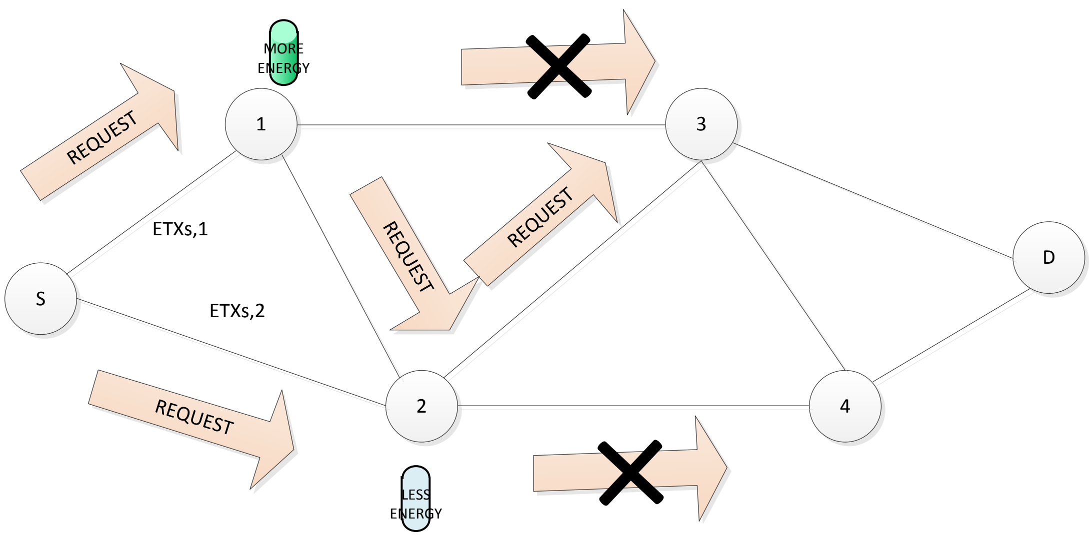

Figure 2.6 Example of EEPR algorithm

$$p = [Pmin + EiA[1 + \frac{(ETX(i-1,i) - ETXmax)}{(1 - ETXmax)}]]^{1/\propto} \quad (5)$$

$$\text{Where} \quad A = \begin{cases} \frac{1-Pmin}{2\times E_{max}^{pre}}, & if, Eavg > Eth \\ \frac{1-Pmin}{2\times E_{max}^{new}}, & if, Eavg \leq Eth \end{cases}$$

- **Merits**

  EEPR algorithm has longer network lifetime and consumes the residual energy of each node more evenly when compared with the typical AODV protocol

- **Demerits**

  In EEPR algorithm the routing setup delay is slightly increased and the routing success probability is slightly decreased.

2.4 Routing protocol based on Energy and Link quality (REL)

Route selection mechanism can be optimized by this protocol by using link quality estimation, energy evaluation and providing load balancing mechanisms, so it increases system's reliability and prevents premature death of nodes [28].

2.4.1 Link quality evaluation in REL:

In this article, the efficiency of the route finding technique of a routing protocol depends on the accuracy of the LQE (Link Quality Estimator) to enhance the protocol reliability

- RSSI (Received-Signal-Strength-Indicator) or LQI (Link-Quality-Indicator) value is used to measure link quality. By using either RSSI or SNR (Signal to Noise Ratio) or both, LQI is calculated which ranges from 0 to 255. One value is selected as threshold value called LQI_{th}. To provide efficient packet delivery ratio (PDR) optimal threshold value is selected.
- LQI value less than LQI_{th} is considered bad and that link with that value is called as weak link and LQI value more than LQI_{th} is considered good and Counter for weak links is increased.
- RREQ and RREP messages contain weak links information and this information is updated at every hop while finding path. After receiving RREP and RREQ message LQI value is updated by each node. After that, LQI value is compared with LQI_{th}, if it is lesser, than weak links are updated according to need.
- Let us assume LQI_{th} is 175. In **Figure** 2.7 S and E are source and destination nodes and numbers associated with links are LQI values. In root selection process path with minimum number of hops and valid link quality is selected.

- In this fig, path with next hop A has weak links=2, path with next hope C has weak link=3 but path with next hop E has no weak link, path with next hop E is selected. This route provides higher reliability.

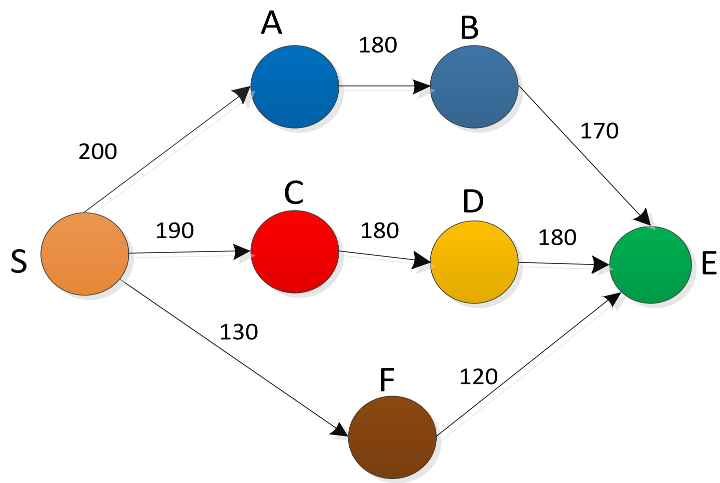

Figure 2.7 quality estimation

In REL, LQI value is analyzed for all received packets continuously. On the basis of average LQI value of present destination, routes are evaluated. In REL n LQI values are stored for every

Destination node and average is computed instead of individuals. Risk of constant switching among available routes hence overhead and delay are reduced by using average values of LQI [27].

2.4.2 Path selection and Load balancing

Load balancing techniques are able to control traffic and distribute the traffic in balanced way among nodes of network, thus increase Quality of Service (minimized delay and packet loss) and decrease use of energy.

- The values of three matrices are managed by REL to find best available path are following-residual energy, link quality based on weak links, and hop count to minimize long and inefficient paths.
- For path selection process, there are two threshold values, first threshold is E_{th}(Energy threshold) used in load balancing technique and finding route. Second threshold is $HCdifference_{max\_permit}$ (Maximum-hop-count-Difference) which calculate the maximum difference of hop to present path.
- The prime technique of fault tolerance and load balancing in WSNs/IoT applications is the usage of multiple routes to control traffic along various paths. By using multiple paths, throughput and data reliability can be increased by balancing utilized energy and bandwidth aggregation.
- To optimize load balancing, the *Eth* corresponds to the monitoring of various energy levels is observed for every node individually. When execution (bootstrap phase) of network starts, percentage of residual energy has to be stored by every node and, the present energy level E_t is compared with previous energy level $E_{(t-1)}$,after each t time units by each node.
- An energy event of discharge is indicated if E_{th} is less than the difference between E_t and $E_{(t-1)}$ or a charging of the battery is needed.
- For uniform energy consumption among the nodes inside network, Eth value should be low [28].

- **Merits**

  REL algorithm provides route with good link quality and efficient energy consumption.

- **Demerits**

  REL algorithm provides less routing success probability and routing set up delay is also increased.

CHAPTER 3

PROPOSED WORK

Routing protocol based on Energy, Link quality and Distance (RELD)

3.1 Overview

In Internet of Things communication takes place among various smart devices and these smart devices may be differed in functionalities. These devices may be sensors, smart phones, smart refrigerators and other smart devices and may be in large numbers, when they communicate each other, then a network is created and these devices are called nodes inside these types of networks.

There are various routing techniques are used to provide efficient communication between various nodes inside the network like EEPR, REL etc., Various QoS factors like Energy, link quality, network life time, reliability, are optimized by these routing techniques.

All these factors are very important in Internet of Things based application while communication. But these protocols have some drawbacks as already discussed above.

So the proposed routing algorithm overcome these drawbacks and solve the problems related to these issues in IoT based applications such as smart homes, environmental monitoring, smart cities, healthcare etc.

The proposed protocol used the greedy forwarding approach Enhanced Range-DIR that restricts the flooding. A greedy node is selected and the packet is forwarded towards the destination. So it increases routing success probability and decreases route setup delay while packet transmission. And also saves the bandwidth by avoiding unnecessary transmission

3.2 The phases of proposed algorithm

The various phases of proposed algorithm are explained as

1. Find set of routes in given network between source node and destination node using ER-DIR algorithm.
2. Route distance evaluation of set of routes selected between source node and destination node.
3. Link quality evaluation of set of routes between source node and destination node.
4. Energy evaluation of nodes inside set of routes between source node and destination node.
5. Find optimum route from already selected set of routes using RELD algorithm to minimize route setup delay, to increase routing success probability, to utilize link and energy efficiently

3.2.1 Enhanced Range Directional Routing (ER-DIR)

ER-DIR algorithm provides different possible routes as output and that output is used as input in RELD algorithm to find optimum path from source to destination inside the network. The proposed algorithm is explained in various steps as shown below

---

Algorithm: ER-DIR

Input: (Current Node, neighbor Node, Destination Node)

Process:

1. N = number of neighbor nodes of current node inside Range-DIR region.
2. m_1 = the slope of current node $(a_1, b_1)$and neighbor node (a_2, b_2).
3. m_2 = the slope of current node $(a_1, b_1)$and destination node (a_2, b_2).
4. M = Angle between slope m_1 and m_2.
5. $m_1 = (b_2 - b_1)/(a_2 - a_1)$;
6. $m_2 = (b_3 - b_1)/(a_3 - a_1)$;
7. $M = \tan^{-1}((m_2 - m_1)/(1 + m_1 m_2))$;
8. Find all neighbor nodes of current node inside Range-DIR region.

9. If (N > 0) then
10. Select all neighbor nodes of current node in parallel manner inside Range-DIR region to find different route through them but in increasing order of angle (M).
11. else
12. Select one nearest angle (M) node, out of this region.
13. Set current node = neighbor node
14. Repeat steps 1 to 13 until we find every route in range-DIR region from source node to destination node.

Output: A set of different routes (S_i) between source node and destination node.

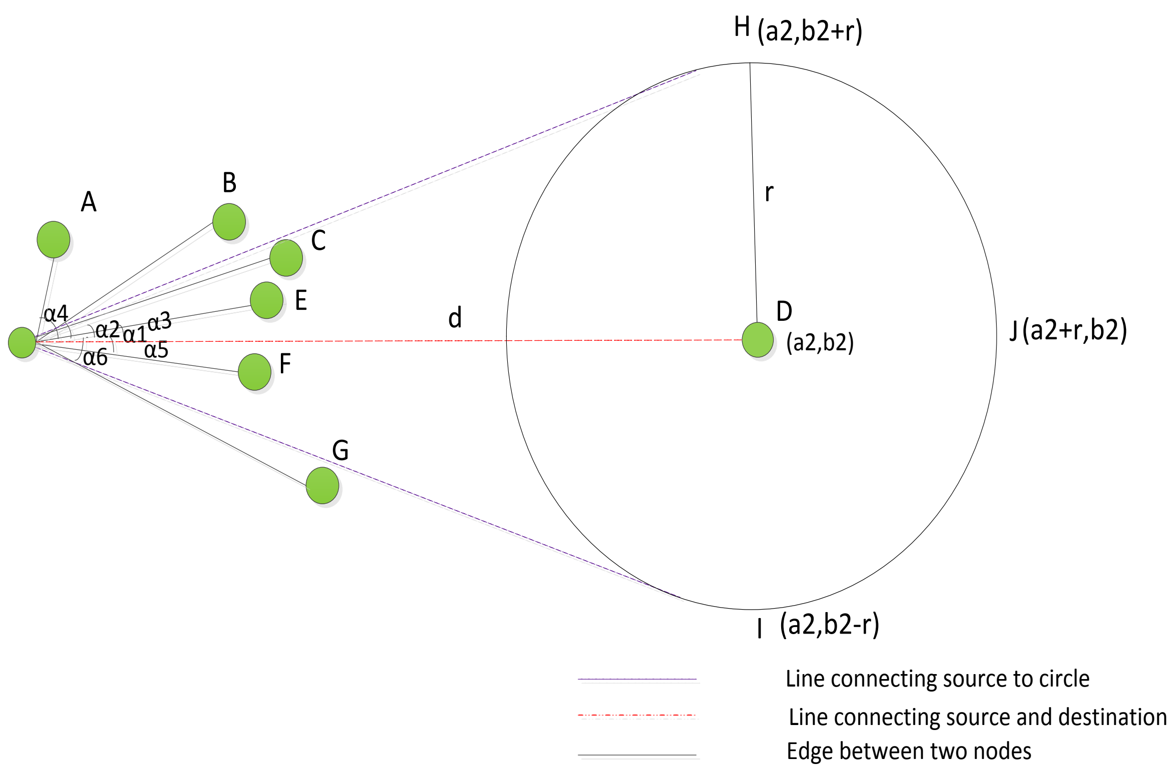

Figure 3.1 Selection of neighbor nodes based on angle

3.2.1.1 Working of ER-DIR algorithm

ER-DIR algorithm is explained using figure 3.1 and figure 3.2 in various steps.

- According to **Figure** 3.1, S is source node and D is destination node.

- Circle enclosing destination node is expected region of destination node D.
- While $\propto_i$ where i = 1 to 6 shows angle between line connecting node S to node D and edge between node S and its neighbor nodes.
- Region SHI is Range-DIR region, nodes inside this area are selected for packet transmission.
- So nodes C, E and F are inside this area and selected as neighbor node of S for packet forwarding, other neighbor nodes A, B and G are not selected.
- Among these nodes C, E and F, Edge connecting S and E makes minimum angle α1 with line SD.
- So first select node E as a neighbor node of node S for packet forwarding, then select node F, after it node C as a neighbor node of node S.
- Then same procedure is applied for nodes E, C and F as a source node inside region SHI.

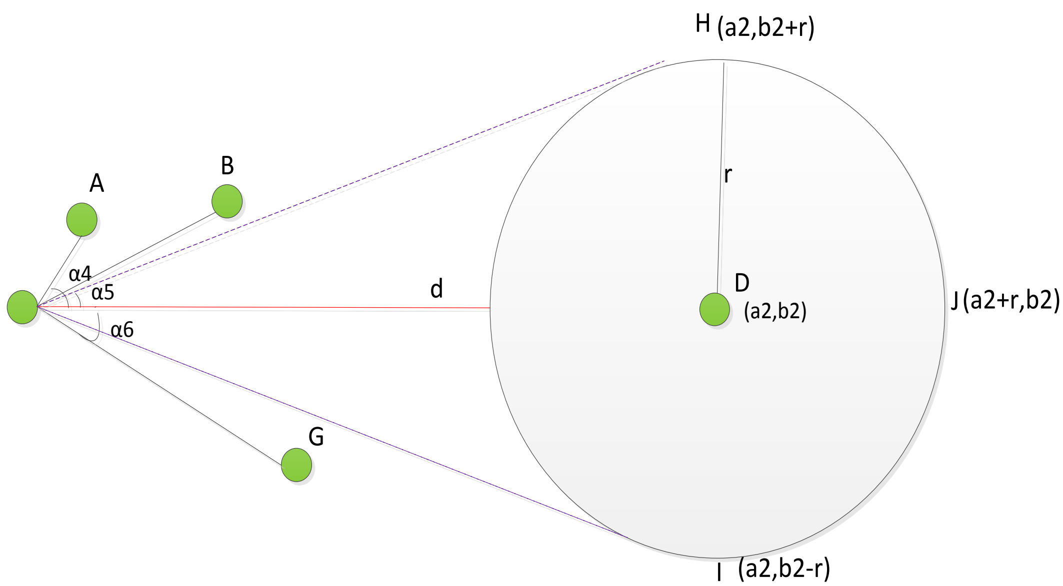

Figure 3.2 Selection of neighbor nodes based on angle when no neighbor node inside Range-DIR region

- But in **Figure** 3.2 there is no neighbor node of Source node S inside Range-DIR region SHI, than both neighbor nodes B and G are included for path selection, out of SHI region.
- But node B makes lesser angle to line SD rather than node G, then neighbor node B is selected for packet forwarding.
- This procedure is applied until all the routes from source node S to destination node D is found inside region SHI.
- Then to find optimum route from source node S to destination node D, RELD algorithm is applied, which find path with efficient energy consumption, efficient link to link quality, lesser route setup delay and better routing success probability.

3.2.1.2 Measurement of Range –DIR region

How to measure area of Range-DIR region is explained in following steps.

- Let source node S with coordinate (a_1, b_1) and destination node D with coordinate(a_2, b_2). Let radius of expected region is r.
- Distance between source node and destination node is d and calculated by equation 3.1,

$$d = \sqrt{(a_2 - a_1)^2 + (b_2 - b_1)^2}; \qquad (3.1)$$

- then area(A) of Range-DIR region is calculated as according to Fig 3.1 by equation 3.2,

$$A = area(SHD) + area(SID) + area(HJID)$$

$$A = \frac{dr}{2} + \frac{dr}{2} + \frac{\pi r^2}{2};$$

$$A = dr + \frac{\pi r^2}{2}; \qquad (3.2)$$

3.2.2 Route Distance calculation

Route distance is one of the metric used in RELD algorithm and calculated using various steps

- Distance between two nodes with coordinates (a_1, b_1) and $(a_2,\ b_2)$ is calculated using following formula given in equation 3.3

$$Distance = \sqrt{(a_2 - a_1)^2 + (b_2 - b_1)^2}\ ; \tag{3.3}$$

- Distance of one route is calculated by adding distance between all intermediate nodes from source node to destination node.
- One value of distance is selected as threshold value that is called Distance threshold(D^{th}), which is selected with respect to straight distance (d) from source node to destination node.
- This D^{th} value is chosen to increase routing success probability.

3.2.3 Link quality evaluation

Link quality is measured in terms of either Link Quality Indicator (LQI) or Receiver Signal Strength Indicator (RSSI) in following way.

- Optimal threshold value (LQI_{th}) is selected to provide optimal packet delivery ratio (PDR).
- Link is divided in to good links and weak links on the basis of LQI_{th} value, if it is lesser than LQI value and more than LQI value respectively.
- While finding path sender node sends Route Request (RREQ) message and receiver node sends Route Reply (RREP) message.
- Both messages contain LQI information of link and this information is updated at every hope. If it is weak link then updated if required.
- On the basis of average LQI value of present destination, routes are evaluated.
- In REL, n LQI values are stored for every destination and average is computed instead of individuals.

- Risk of constant switching among available routes hence overhead and delay are reduced by using average values of LQI.

3.2.4 Energy evaluation

The consumption of energy by each node is required in balanced way. There is procedure for energy consumption.

- For energy evaluation one threshold value, Energy threshold (E^{th}) is selected, which is used in load balancing.
- In starting phase of execution in the network, percentage of residual energy has to be stored by every node and, the present energy level E_t is compared with previous energy level$E_{(t-1)}$, after each t time units by each node.
- An energy event of discharge is indicated if Eth is less than the difference between E_t and $E_{(t-1)}$ which is called $(Index_{RADV})$ or a charging of the battery is needed.
- Difference of energy consumption in the nodes is dependent on the Energy threshold (E^{th}) value.
- If E^{th} value is high then there is large difference in energy consumption while if E^{th} value is low then it results uniform energy consumption despite of RADV notification will be more.

3.2.5 Optimum Path Algorithm

The route finding process involves sending RREQ and RREP message using ER-DIR algorithm. These messages also collect information about route distance, link quality and residual energy in route searching process. These messages require three additional fields to report about these three metrics to every possible path searched using ER-DIR algorithm. Each received RREP message is confirmation of one route to destination.

In optimum path algorithm, for path selection process two threshold parameters are considered, first one is Energy threshold (Eth) which is used for load balancing and second is Distance threshold (D^{th}) which is used to optimize route set up delay and routing success probability.

Algorithm: RELD

Notations:

D^{th}: Distance threshold
E^{th}: Energy threshold
R_c: Current route
R_n: New route
E_c : Energy of current route
E_n : Energy of new route
D_c : Distance of current route
D_n : Distance of new route
Bl_c : Bad links of current route
Bl_n : Bad links of new route
GoToRoute(): function to switch between current route and new route.

Input: A set of different routes (S_i)
Process:

1. if $E_c = E_n$ then
2. if $D_c > D_n + D^{th}$ then
3. if $Bl_c \geq Bl_n$ then
4. GoToRoute (R_n)
5. end if
6. end if
7. else if $E_c < E_n$ then
8. if $D_c + D^{th} \geq D_n$ then
9. if $Bl_c \geq Bl_n$ then
10. GoToRoute (R_n)
11. end if
12. end if
13. else if $E_c > E_n$ and $E_c \leq E_n + E^{th}$ then
14. if $D_c > D_n + D^{th}$ and $Bl_c \geq Bl_n$ then
15. GoToRoute (R_n)
16. end if
17. end if

Output: Final route from source node to destination node after optimizing energy, link-to-link quality, route setup delay and routing success probability.

CHAPTER 4

SIMULATION AND RESULTS

4.1 Simulation setup

This chapter provides a description of simulation and result for the proposed RELD routing algorithm. This proposed RELD algorithm is an improvement on REL protocol in respect of routing success probability and route setup delay. The tool used to simulate our work is Matlab 2009b.

The simulation parameters used for studying RELD algorithm are as below.

Table1. Simulation parameters

Parameters	**Values**
Area	200 m $\times$ 200 m
Number of Nodes	100
Topology	Uniform
Simulation time	60 min
Base station Location	(60,60)
Inter Packet Interval	2 s
Initial Energy	17565 J (2 AA batteries)
E^{th}	2
LQI_{th}	200
D^{th}	12 m

This comparison provides an idea about our protocol working in terms of route setup delay and routing success probability associated in comparison to REL.

The proposed algorithm mainly focuses on the improvement in control packets generation. Thus we here analytically analyze the improvement in our protocol over REL in respect of routing success probability and route setup delay, which are a major concern for any routing protocol's scalability, throughput, and delay.

4.2 Discussion Parameters

In this simulation, we compare the performance of RELD algorithm on various parameters like, route setup delay, routing success probability and Packet delivery ratio (PDR).

Route setup delay is described as the time difference between the time when a source node forwards the RREQ packets and the time when destination node receives the first RREQ packet. This route setup delay is minimized by minimizing the collision during packet forwarding.

Routing success probability is defined as probability of success in packet forwarding from source node to destination node. Routing success probability is directly proportional to route distance. These performance metrics are then compared against REL protocol with various numbers of established connections in the networks.

Simulation results provide us Distance threshold (D^{th}), LQI threshold (LQI^{th}) and Energy threshold (E^{th})of the simulation. On the basis of these parameters route setup delay and routing success probability are resulted in simulation.

4.3 Results

Here, we compare and discusses the RELD algorithm's results in terms of route setup delay, routing success probability associated with its operation and also simulate the distance threshold (D^{th}).

4.2.1 Simulation for distance threshold

Figure 4.1 shows PDR for various values of D^{th} which changes from 4 to 20 $meters$. PDR is higher than desired, *i.e.*, 80% for each possible value. Therefore, values more than 12 meters create more paths and the signaling overhead can have a negative effect on routing success probability and delay. According to our results, the most appropriate values for D^{th} are 8 $meters$ and 12 $meters$. In our simulation experiments, 12 $meters$ is selected as D^{th} value to avoid a small number of alternate paths. The value 12 $meters$ is able to consider more routes and attain a better PDR result, as shown in **Figure** 4.1.

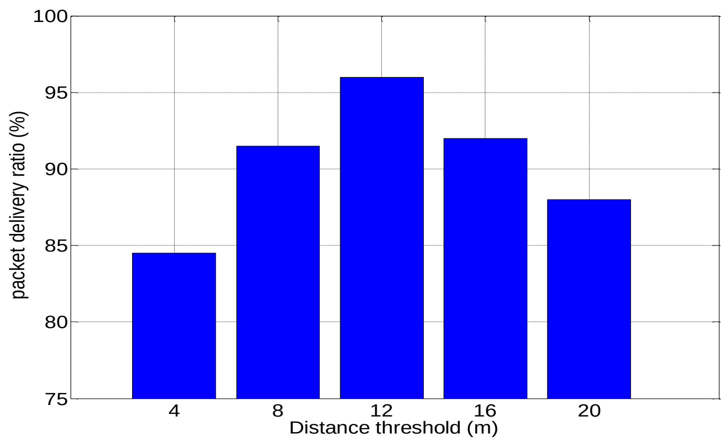

Figure 4.1 Simulation result of Distance threshold(D^{th})

4.3.1 Case 1: Route setup delay comparison with REL

This comparison provides an idea about our protocol working in terms of route setup delay associated in comparison to REL protocol.

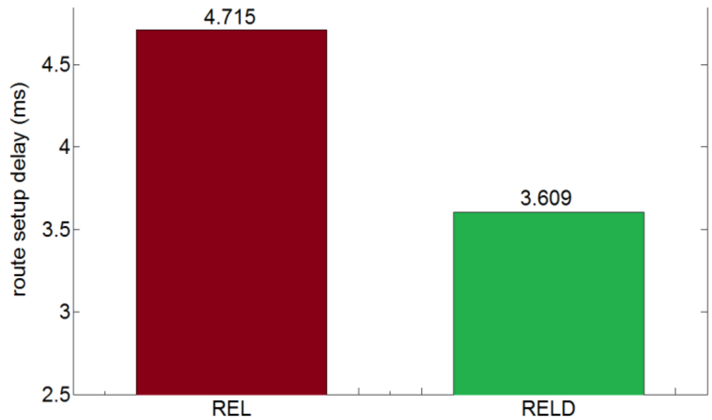

Figure 4.2 Route setup delay

Route setup delay is described as the time difference between the time when a source node forwards the RREQ packets and the time when destination node receives the first RREQ packet. Route setup delay is directly proportional to collision. RELD protocol uses ER-DIR algorithm for route setup which minimize collision during packet forwarding as compare to REL protocol which uses flooding. **Figure** 4.2 shows the result of route setup delay. The route setup delay under the RELD algorithm has approximately $1.106\,ms$ lesser than that under the typical REL protocol.

4.3.2 Case 2: Routing success probability comparison with REL

This comparison provides an idea about our protocol working in terms of routing success probability associated in comparison to REL's routing success probability.

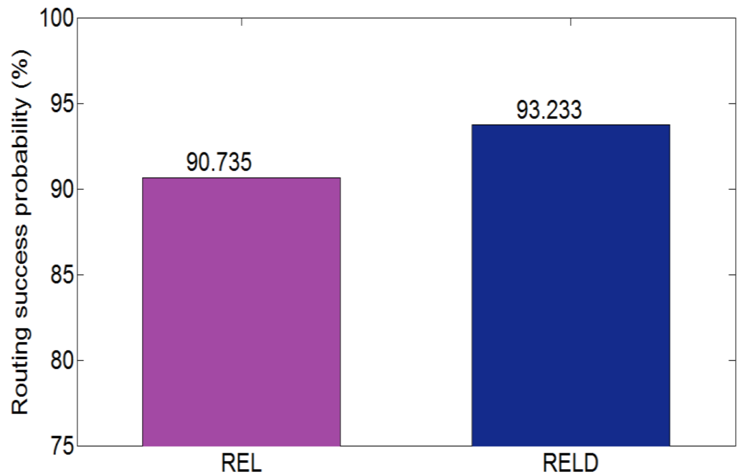

Figure 4.3 Routing success probability

Here, finally our results beat the REL protocol in terms of routing success probability associated with network maintenance and route finding. Route distance is decreased in RELD protocol and routing success probability decreases as distance decreases.

The result for the routing success probability in **Figure** 4.3 shows that the routing success probability of the typical REL protocol is 90.735%, whereas that of the RELD algorithm is 93.233%. It is approximately 2.5 % higher than that of the typical RELD protocol.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The main objective of this protocol was to enhance routing success probability and to reduce route setup delay while considering the energy efficiency and link quality during route selection from source node to destination node in a network. The design of this protocol and its analysis theoretically prove that RELD protocol minimizes route setup delay and enhances routing success probability of the network. In particular, using RELD protocol routing success probability is enhanced from 90.735% to 93.233% as compared to REL protocol in IoT. The protocol reduces route setup delay from $4.715\ ms$ to $3.609\ ms$ as compared to REL.

5.2 Future work

Algorithm considered in this dissertation, works well in static environment. It is very simple and easy to modify as per the application requirement. In future work, authors will enhance the algorithm considering throughput and packet delivery ratio as performance metric by modifying the design. Adaptability in a dynamic network environment will be also explored. Adjustment of the radios/transmissions to reduce energy consumption will also be a challenging task for future work.

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