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Design of an Energy Aware Multicast Routing Protocol with Optimal QoS Support over IoT Networks – EAMRO

[1] J. Jayabharathi, [2] Dr. R. Saminathan, [3] Dr. S. Saravanan
[1] Research Scholar, [2][3] Assistant Professor
[1][2][3] Department of Computer Science & Engineering, Annamalai University Annamalainagar – 608 002 Tamil Nadu, India

Abstract: **- Researches in field of QoS and energy supportive approaches in IoT networks nodes primarily focus on node inter connectivity and packet transmission, packet collision during transmission and optimize network lifetime. Majority of QoS and energy supportive algorithms in IoT networks focus on providing route management and effective data transmissions, supportive energy dissipation on the transmission route. EAMRO, the proposed algorithm lead to maximal node utilization, as well as decrease on node energy used during transmission on selected route. Consistent demand on QoS and controlled energy consumption is always felt by researching community. This paper proposes an energy controlled QoS support routing scheme EAMRO for IoT node location systems where demand for services are high. EAMRO suggests an optimal energy identification approach for selection of a data transmission route, along with route identification based on ratio of energy identified and its corresponding distance to destination node as location aware to solve the problem. Providing optimal QoS is controlled by assigning a least transmission power to the nodes where each node is aware of location information and hence able to adjust their transmission power accordingly. EAMRO is simulated using cup carbon simulator whose performance shows minimal energy consumption of sensor nodes compared to RPL.**

Keywords**: Energy utilization, Optimal route, IoT networks, QoS utilization**

I. INTRODUCTION

Internet of Things (IoT) can be defined as a platform where every service can be considered as multiple devices which integrate to become smarter, processing being intelligent, and communication involves being informative [4]. Such IoT network supports towards multiple applications involving pervasive computing, machine learning and VLSI technology. IoT networks consists of largely deployed sensor nodes which has limited battery power with additional feature of mobility, limited memory capacity, minimal processing capabilities, capacity to handle minimal resource, need for energy conservation, which forms the basis of designing proactive routing protocols. Sensor nodes defined over IoT networks possess the capability to organize into a self supportive network, where defined nodes in networks are highly susceptible to dynamic change in topology in respect of random mobility and consistent support on demand for service specific bandwidth. However, IoT networks fall behind due to constraints in energy supply and bandwidth, such that when combined with deployment of large number of nodes, they pose many challenges to the design and management of networks. These challenges necessitates on QoS support and energy-awareness at each layers of IP networking protocol stack [6] which focus on physical and link layers alone, hence demand for research in these domains focus on system-level energy conservation such as scaling over dynamic voltage, radio communication hardware, low duty cycle issues, system partitioning, and energy aware MAC protocols. Multiple challenges towards development of QoS based routing schemes has been provoked as research issue with effect on energy management over differential service aware system, which can actuate or respond to any change of event over a defined time interval. Major research works [13] [14] in field of IoT networks focuses on QoS provisioning, which works towards optimal route identification between multiple IoT source nodes and IoT receiver nodes belonging to multiple domains or clusters. Though multiple research works have been carried out towards route identification based on energy aware of IoT networks nodes and route prediction has much impact on real time implementation and applications. Much less work had been carried out on energy aware routing based on service capacity of IoT networks node [7] [16]. Even though service type and energy utilization of a wireless sensory node plays vital role towards route identification, its complexity lies in varying IoT networks topology. Supporting on challenges in routing "energy-aware"ness with provisioning of QoS are unique to IoT networks, which highly demands to change in node topology, multi-hop data transfer and sharing of wireless medium increase the data transmission complexity of network. Nodes in IoT networks can achieve the expected QoS primarily based on node mobility, sensing range of node is effectively understood before any transmission [12]. Any IoT node which may be within interference range of another node when trying to transmit simultaneously or intermittently may lead to data collisions, attempting for re-transmission may lead to signal collisions and hence data loss. Such efforts of retransmissions and signal interferences lead to additional energy consumption and extra latency from retransmissions increases the link delay. The behavior of QoS routing depends on end-to-end channel interference, round trip lifetime, end-to-end packet delay are referred as route metrics while noise, sender signal strength, receiver signal strength relate to energy consumed.

The proposed approach EAMRO, enforces on improvement of performance of IoT networks based on optimal route identification and selection based on defined energy capacity (Joules) of each node engaged in service capacity of nodes towards transmission over any source node and sink. Identifying the optimal QoS over IoT networks depends on multiple sensitive metrics such as node communication range, interference ratio, topology of node, location management issues, type of service in use. Node link information supports on congestion control information, which is defined as ratio of periodically measured arrival rate (input) and service rate (output). The essential requirement for QoS computation under congested scenario can be evaluated under the operational network throughput along the information inconsistency and topology uncertainty.

EAMRO works on following research phenomena :

i Identifying the nodes based on each session throughput, multiple routes in use and dynamic uncertain topology.

ii Need for energy consumed of a node to determine the QoS resulting in throughput based optimal scheduling algorithm to stabilize the network

iii Design an algorithm whose information and computation complexity is independent of the network size

II. LITERATURE SURVEY

An in-depth survey and review is carried out to analyze the existing effective IoT networks routing protocols which focus on establishing routing paths and node energy [6][14]. Dujovne [5], work elaborates support to QoS in IoT networks as well as analyzed the QoS requirements imposed by the major applications of IoT networks. An intensive research and analysis had been conducted on data aggregation routing, but the important MAC layer retransmission issue as described above has been relatively seldom addressed. Arunkumar et al [4], work on IoT networks routing approach which discuss on suboptimal aggregation heuristics models such as Center at Nearest Source (CNS), Shortest Paths Tree (SPT) and Greedy Incremental Tree (GIT). Throughput of CNS and SPT over IoT networks are found similar to TOPSI protocol of adhoc networks, yet the throughput of these schemes are not found to be effective in terms of data loss and path establishment. Energy consumption being a tradeoff between the data aggregation and retransmission in IoT / sensor network by using the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) MAC protocol is discussed by Lin[9]. Though, the energy consumption framework does not discuss about the power consumption in sleep mode, which make the proposed algorithm to fail in identifying an energy efficient data aggregation tree. In addition, retransmission latency is not considered in this work, hence that it does not guarantee the delay QoS.

Sankarasubramaniam, et al [15] work discusses on good survey of routing protocols on IoT and sensor networks. The work reports on multiple protocols, where flooding approach focuses on relaying messages from the source node to all other active nodes in that network. The major drawback observed in flooding is redundancy of messages, complexity and it is not energy aware. Gossiping [12] is another proposed algorithm to overcome the drawbacks of flooding. Here the node selects one of its neighbor nodes and sends the data to that particular node and this process continues until the message reaches the destination node, hence the redundancy and complexity decreases.

Power Aware Sectoring based Clustering ALgorithm for Wireless Sensor Networks (PASCAL) is proposed [9] with design aspects of leveling, sectoring and implementation of clustering methods. The routing algorithm considers IoT network nodes to be static or have a very low mobility with respect to signal propagation. In this algorithm, the packets are forwarded by flooding. The concept of node switching introduced in RPL [16] helps to improve the lifetime of the sensor network. Shah. and Rabaey [14] defined an energy aware with source aware protocol focusing on IoT networks routing protocol. This protocol defines a local information routing protocol, where each node maintains the neighbor node's information. Similarly each node will transmit a packet to its known neighbor, which is closer to the destination. This process continues, until the packet reaches the destination. Directional Value (DV) parameter is used to choose a neighbor node to forward the packet.

Routing Protocol for Low-Power and Lossy (RPL) [15] can be defined as distance-vector protocol which does support multiple data-link protocols and generates data-centric routing mechanism. RPL adopts naming procedure as a directed graph maintaining data as high level descriptors or meta-data. During transmission, RPL uses multiple sensor's

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meta-data to be exchanged between sensors through data advertisement mechanism [5] in order to select an adaptive route for data transmission. This approach resolves the issue of data flooding which includes resource blindness, redundant information passing, sensitive areas overlapping and adaptive energy efficiency. Raghunathan [11] adopts a set of sub-optimal paths occasionally to increase the lifetime of the network. These paths are chosen by means of a probability function, which depends on the energy consumption of each path. This approach argues that usage of minimum energy path all the time will deplete the energy of nodes on that path, while multiple paths is used with a certain probability so that the whole network lifetime increases. Karagiannis, et al [7] defined hierarchical routing algorithms for low energy aware cluster computing which forms clusters of the sensor nodes based on its received signal strength and utilization of local cluster heads as routers to the sink. This approach consumes less energy, since the transmissions between nodes is carried out by cluster heads rather than all sensor nodes. Optimal number of cluster heads is estimated to be 5% of the total number of nodes.

Channel -Aware Routing Protocol (CARP) [4] is defined as a distributed routing protocol specifically proposed for devices in underwater communication. CARP is used for IoT setup primarily due to its lightweight packets and architecture. This approach defines link quality as a major metric for QoS analysis that can be computed based on any successful data transmission gathered from all neighboring sensors, and selected to forwarding nodes. Krishnamachari, et al [8] defined CORPL which is considered as an extension of RPL to be proposed as cognitive RPL, specifically defined for cognitive networks. This approach adopts DODAG topology generation with major modifications to RPL protocol. CORPL utilizes opportunistic forwarding approach to forward assigned data packet and choosing multiple forwarders, coordinates between IoT nodes which select available best "next hop" to forward packet to next node.

Perillo and W. Heinzelman [13] proposes a new reliable communication scheme for intelligent transfer for IoT networks. This scheme is a novel solution developed to achieve reliable event detection in IoT networks with minimum energy expenditure. Pottie and W. Kaiser[12] provide application QoS through the joint optimization of sensor scheduling and data routing, which can also extend the lifetime of a network considerably compared to approaches that do not use intelligent scheduling, even when combined with energy aware routing algorithms.

EAMRO algorithm keeps anvil of energy consumption of all nodes in transmission within its domain range, since any failure of a node due to less energy node may lead to loss of data. Selection of a node with less energy may lead to link or node failure such that reconfiguration of the network and re-computation of the routing paths, route selection in each communication pattern results in reduced QoS as well as degrades the network lifetime. Optimal route selection leads to selection of short routes resulting with depletion in batteries. Hence, this work focuses on end-to-end channel awareness and end-to-end channel quality in terms of path lifetimes.

III. EAMRO

Major task of an IOT network supported sensor node focuses on mechanisms to collect data, perform data aggregation, transmit as well as monitor / control events based on node's processing capability [1]. Any efficient energy aware routing algorithm for IoT supported sensor network focus on procedures:

a) To decrease the end-to-end delay and improve session life time.
b) Necessitate on strategies to improve the network reliability
c) To suggest on power consumption reduction during data transmission and processing which suggests on extending the lifetime of network.

Hence, EAMRO algorithm is designed to guarantee "on demand" QoS [2] while considers limited energy supply available in nodes. The lifetime of a node is strictly bounded to available energy, the algorithm is expected to utilize active nodes during communication as well as conserve their energy. Focus on energy control procedures over QoS routing is a major factor to determine the life of a sensor network, since sensor nodes are driven by battery and have very low energy resources. The major objective of EAMRO is to maximize the network lifetime by carefully defining link cost as a function of node remaining energy and the required transmission energy using that link. EAMRO's principle and frame work is as follows:

1. To identify any change in traffic pattern of nodes route / update of node in the network.
2. To identify and eliminate the redundancy of information in the base station
3. To identify the failed nodes and assign their duties to some other nodes
4. To combine the residual energy of the sensor nodes.

3.1 Energy Aware model

A simple energy model [7] is adopted where each node starts with the same initial energy and forwards a packet by consuming one unit of energy. Initially, all IoT networks nodes are assumed to have similar energy level.

Notations proposed in work:

N - Set of IoT networks nodes engaged in communication, where N= (n_a, n_b …n_m)

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D - Maximal observed propagation delay for transmitting data packets
p - Rate of Packet arrival
S - Source node
s - Sink node
R_n - Set of possible transmission radius that node n can adopt, which is a set of discrete elements
en (r_n) - Energy consumption function of node n, which is a function of node's transmission radius
E_{idle} - Energy consumption per unit time when sensor nodes are operating in the idle mode
TR - Transmission Range of nodes
TR_n - Transmission radius of node 'n'
Metrics adopted for QoS analysis:
L (bits) - Size of a data transmission (including headers)
B (bps) - Transmission rate of sensor node
tx (ms) - Time taken to transmit a data packet
Ei (ms)- Maximum energy life time routing
Nri (J)- Residual energy utilized in a node
Nui (J) – Energy Utilization in a node
Se (ms)- Session Life Time

The Cost function (C) for the protocol captures the effect of delay, throughput and energy consumption from any node to the sink. The link cost LCi is a function that captures the nodes' energy reserve, transmission energy, energy rate and other communication parameters.

Theorem :

Consider an undirected graph G (V,E) [Fig. 1], where G $\subset$ V, such that no two nodes in the subset (node 'i' range of communication) defines an edge, which can be defined as distance 'di' between nodes n_a and n_b. For every vertex V $\subset$ G, let there exists a vertex V`, such that V $\subseteq$ V`, $\forall$ node n_a $\in$V, hence n_a $\exists$ V`.

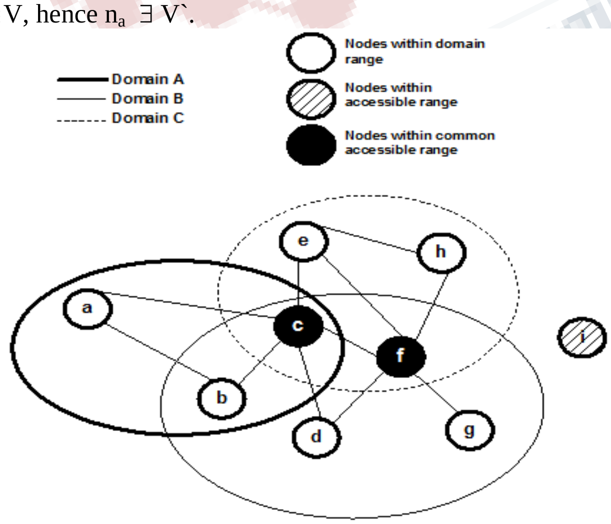

Fig. 1 IoT Networks forming a Graph Network on Mobility

Fig. 1 show multiple neighbor IoT networks topology, where node 'c' is represented with 2 edges namely 'a','b', similarly other nodes 'b', 'c', 'd' and 'e' are represented by corresponding edges. Each vertex gets connected to its neighboring vertices such as 'a', 'b', 'c', 'd' and 'e'. Since each node knows about its location and also about its neighbors' location by directional values, the proposed algorithm can send its message from the defined source to any destination as well as receive messages.

Each node adopts the following properties,

i. Each IoT node in network is assigned a unique ID.
ii. Each node maintains the relative distance 'di' between nodes (ie., total perimeter of set of nodes in a communication range in each direction).
iii. Each node can compute the relative direction of another node from its ID.

IoT nodes within a specific range 'r' are located on a euclidian plane such that each node adapts to transmission range TR $\in$ [rmax, rmin]. Here, rmax, rmin are defined as the maximum and minimum signal strength of node na through which nodes can transmit data or communicate. Graph G can be defined as set of vertices and edges between any two nodes (ei,ej) $\in$ E, if and only if distance 'di' between two nodes na, nb whose vertices d(vi,vj) $\leq$ TR here d(vi,vj) denote the Euclidean distance between vertices vi and vj. To model the behavior of energy utilization in IoT networks, it can be assumed that every node 'n' starts with the same initial energy 'e0' and forwards a packet 'pi' by consuming 'j' unit of energy.

The algorithm is structured such that data-fusion reduces the required buffer of data transmission [14] between multiple nodes engaged in communication. The decision of identifying appropriate node for transmission is determined dynamically at each interval which depends on node properties as discussed in EAMRO_transmit ( ). The decision of selecting a node for forwarding the data is highly vital in research, since it minimizes the energy utilization overhead which is solely deterministic of each node independent of other nodes to minimize overhead in cluster-head establishment [11]. This decision is a function of the percentage of optimal cluster-heads in a network (determined a priori on application), in combination with how often and the last time a given node has been a cluster head in the past [13].

The energy consumption E(n) for data transmission between any set of nodes (units in joules):

$E(n_a) = ET + ER + \alpha a$

$ET = a \text{ x } (e_m + e_a \times di\ n_a) + a \times e_r$

Here,

ET = energy consumptions of transmitting data

ER = energy consumptions of receiving data

Observed energy dissipations noticed during operation of transmitter radio (e_a), transmitter amplifier (e_m) and receiver radio (e_r).
di is the distance between any two nodes na and nb
n is the parameter of power attenuation with ($0 \leq n \leq 1$).
α is the energy (0.001)
$r = e_a - e_r$
Hence, $E(n) = ET – ER / (1 – di(n_a- n_b) \times R \pmod{1/r})$, iff $n_a, n_b \in N$

Initially nodes need to understand only the location information of their direct neighbors in order to forward packets. Second, such protocols conserve energy and bandwidth since discovery floods and state propagation are not required beyond a single hop. This approach to routing involves relaying the message to one of its neighbors that is geographically closest to the destination node. Any node that requires sending a message acquires the address of the destination, while preparing the transmission message, and calculates the distance between any two communicatable nodes from a source to destination. Next, it calculates distance from each of its neighbors to the destination.

3.2 EAMRO algorithm

EAMRO algorithm works on assumption of IoT networks nodes located within a region, such that their intermediate distance is relative to their signal strength. Any node which sends data or receives data consumes energy, if and only if an optimal multi-hop route is identified or selected. EAMRO algorithm adopts the following assumptions:

[a] Event Handling: If any event is noticed at a node, then the node floods data packets to every of its neighbor [8].
[b] Data Handling: Only the nodes which are in WAKE mode will receive data packets while nodes in SLEEP mode don't support on receiving data packets. The nodes which receive data packets check its node ID along with assigned packet ID.
[c] Error Handling: Any missing sequence number of packet denotes dropping of packet or loss as well as duplication of packet which suggests packet mislead.

```
EAMRO_TRANSMIT ( )
Input :  [a] Data sent / received by IOT sensor node.
         [b] Transmission Power of node
         [c] TSRSS :  Transmission Send Receive Signal
Strength of node
         [d] ARSSI : Average TSRSS
         [e] AEED : Average End to End Delay

Output: QoS metrics, Average Rate of transmission,
```

```
Packet Loss
For each IoT networks node N

1. Define set of nodes N = {n1, n2, …., nm}
2. Distance di = Minimize (  na,  nb )
   Set di = 1 // initialize the distance to be selected
between nodes

3. Identify the TSRSS ( in any node as mW)
    If SendSigStr ( na) > RecvSigStr ( nb)
        W [ ] =  na,  nb, .. nk // gather nodes of higher signal
strength
        Gather ei // energy of node n in W
        Gather r [ ] // radius of node in range 'R'

4.  while ( W[na] !=NULL) ) {
        SendData ( na, &portno, TCP_Proto, packet, tna ) //
Transmit Data Packet @ tna
         nb  = RecvData ( packet, tnb)
        pktloss = packet( nb) - packet ( na)
        TRSSI = ei * r * pktloss
            goto step-2}
        ARSSI=  TSRSS/N

5.   tna & tnb - the time taken for node  na  and  nb to send
and receive
       do  { // gather hops length for all nodes
          a=1;
          h[a] = Min (tna, tnb)  // Hop to Hop Delay for route
           a++; // another route
        }

6. Find the End to End Delay (EED) for route 'a'
     EED = Max ( W[ ], b[ ] )
    AEED=EED/N

7. do { Compute E (a) where 'a' being the route selected
for transmission }
             if  (h[a] > h[a++] && di < r[ ] )
             E(a) =  AEED * ARSSI
```

IoT networks node acts as both sender and receiver, where Ri is a route computed if an energy efficient node is identified among the available route. Fig. 2a shows neighbour node discovery and route establishment process where node 'a' identifies node 'b' as neighbour node based on EAMRO.

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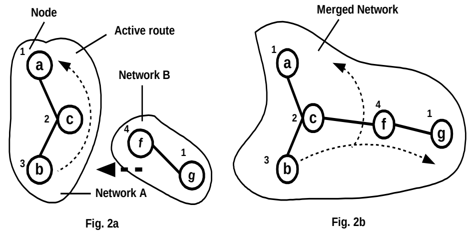

Fig. 2 IoT Networks Nodes forming Active Network

The process of route request and reply between nodes 'b' and 'g' is shown in Fig. 2, which formulates the route as shown in Fig. 2b. Any IoT networks node is part of network if it adopts EAMRO procedure (Fig. 3) and forwards a packet, else it is considered as independent node and is not part of network. To increase the node lifetime for routing over a session established, energy used in intermediate nodes for routing also plays major role. This paper suggests consistent and local energy update of nodes where node is selected only if condition of threshold energy is identified. In this update process, selection and reselection of node with lower than threshold energy decreases the relation of session connectivity. While nodes with upper than threshold energy award session connectivity is conferred. Network lifetime and number of active nodes will increase with EAMRO which had been proved by simulation.

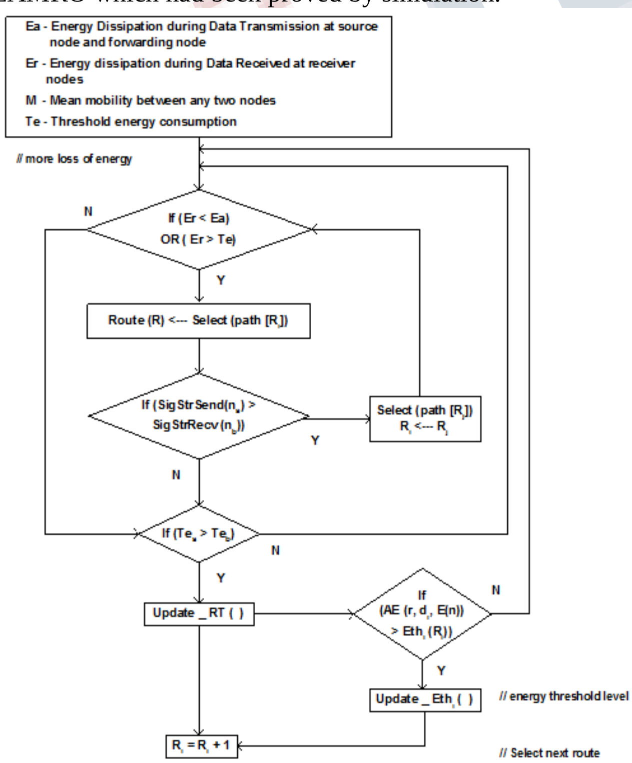

Fig. 3 EAMRO Procedure

IV. EXPERIMENTAL APPROACH

IoT network was simulated in the presence of multiple QoS factors having effect on routing protocols performance. The simulation test-bed works on IoT networks scenario designed with two gateways and wireless interconnected IoT / sensor nodes as per industry standards [10] over Cup Carbon Simulator [3]. The nodes can multicast data /signal packets for transmission during a session established over TOPSI/RPL protocol. Services such as messaging using MQTT can be extended over IoT networks such that nodes participate in routing.

Table 1 Simulation Metrics

Network Layout	500 x 500 m
Number of nodes (N)	300
Energy – Initial	0.01 joules
Frequency	700 Hz
Connectivity range	60 m
Sensing range	30 m
Sink	300,300

Simulation time for each scenario was set to 500 seconds and repetitive simulations for each scenario were performed to verify the reliability of the results. The network was modeled on an area having dimension of 300 x 300 meters. The packet size is of 512 bytes, and the packet rate is 2 packets /sec. All nodes in this network are considered as source nodes communicating with constant bit rate 10 Mbps. The numbers of nodes chosen are 50, 100, 150, 200, 250 and 300 nodes (Table 1) with required set of input parameters. MQTT is the service type used for simulation, where initially, each node uses same energy level. A node whose energy is less than threshold set is considered as dead, which are not selected for simulation. Target node is located within the range of communication such that all data being received can be considered for scenario analysis. Fig. 4 shows interconnected IoT network with 50 nodes involved in communication as data transfer over a river basin.

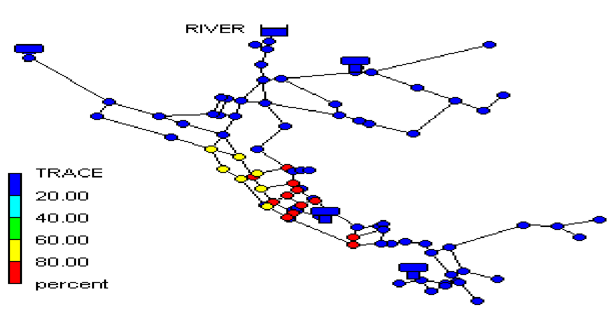

Fig. 4 Interconnected IOT Nodes involved in Communication over Data Transfer of a River Basin

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In the proposed scenario, routing is based on both TOPSI and RPL protocol, defined as lossless, simple routing protocol designed specifically for use in multi-hop wireless IoT networks. RPL supports on the network to be completely self-organizing and self-configuring, with additional support for any existing network infrastructure. The capability of sending route replies using cached routes had been disabled in simulations. The physical layer uses the Direct Sequence Spread Spectrum (DSSS) and data rate was set to 11 Mbps (IEEE 802.11b standard) for WiFi interconnection. Each IoT node transmits the power as set to 0.005W and the packet reception power threshold was set to -95 dBm. The simulation was carried out with data transmission of sensor nodes which are routed to the destination node through multi-hop intermediate nodes. The simulation node size varies between 50 to 300 nodes with 100% active source nodes and implementation assumes random topology for node infra structural setup.

4.1 Analysis

Following are the assumptions to be followed for EAMRO analysis, to support on aspects of QoS and energy conservation with support for optimal route assignment over dynamic node mobility.

Multi-hop ($n \geq 2$) is followed over a dynamic route path.

Measured data over an active period of duty cycle required to transmit packets.

EAMRO algorithm is analyzed with SPIN [10] and RPL algorithm.

Consumption of power from CPU is neglected, but power consumed over data transmission is updated.

Consumption of energy ratio over a designated channel is updated.

Fig. 5 shows the observed throughput in which EAMRO performs better when compared with other approaches such as TOPSI, RPL and SPIN. As the number of nodes increases the throughput saturates i.e., after 90 nodes.

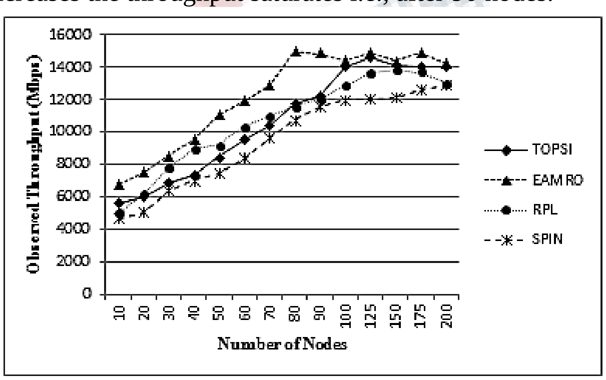

Fig. 5 Observed Throughput with respect to Active Nodes

Fig. 6 shows the delay encountered by RPL and EAMRO for QoS energy handling schemes during the simulation run for scenarios. Fig. 7 shows the observed Packet Delivery Ratio (PDR) in % during routing for IoT networks over a route for a complete round trip. Performance is analyzed over algorithms being used for comparison (Fig. 6), where delay performance of EAMRO is found to be lesser compared to RPL and SPIN approaches.

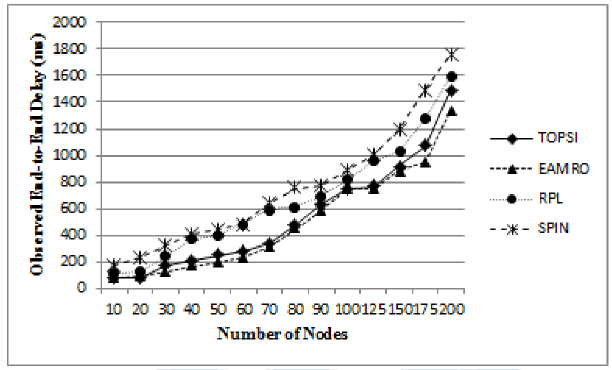

Fig. 6 Observed End-to-End Delay for Energy Consumed during Routing

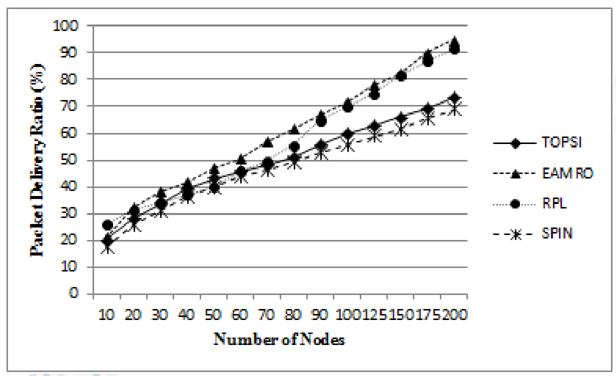

Fig. 7 Observed Packet Delivery Ratio

The results show that EAMRO supports with a consistent optimally improved network life than that of existing QoS based energy conservation schemes such as TOPSI, SPIN.

V. SUMMARY AND FUTURE WORK

Few research efforts have been made in QoS support for IoT networks. The literature survey discusses on analysis of QoS requirements imposed by the main applications of IoT networks, and identified that the end-to-end QoS concept used in traditional networks may not be sufficient in IoT networks. Traditional QoS context of IoT networks employs efficient resource utilization such as bandwidth, but minimal usage of energy should also be considered. Thus, QoS support in IoT networks should include QoS control mechanisms also besides QoS assurance mechanisms employed in traditional networks, which eliminates unnecessary energy consumption in data delivery. EAMRO scheme supports IoT networks in following research aspects, (a) providing required optimal QoS support for IoT networks, (b) controlling and minimizing energy consumption during routing process, (c) providing consistent energy efficiency over a multi-hop IoT networks.

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