Design and Analysis of an Optimized Scheduling Approach using Decision Making over IoT (TOPSI) for Relay based Routing Protocols

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Abstract:- This research work focuses on support towards QoS approaches over IoT using computational models based on scheduling schemes to enable service oriented systems. IoT system supports on application of day-to-day physical tasks with virtual objects which inter-connect to create opportunities for integration of world into computer-based systems. The QoS scheduling model TOPSI implements a top-down decision making process over top to bottom interconnected layers using service supportive optimization algorithms based on demandable QoS requirements and applications. TOPSI adopts Markov Decision Process (MDP) at the three layers from transport layer to application layer which identifies the QoS supportive metrics for IoT and maximizes the service quality at network layer. The connection cost over multiple sessions is stochastic in nature as service is supportive based on decision making algorithms. TOPSI uses QoS attributes adopted in traditional QoS mechanisms based on transmission of sensor data and decision making based on sensing ability. TOPSI model defines and measures the QoS metrics of IoT network using adaptive monitoring module at transport layer for the defined service in use. TOPSI shows optimized throughput for variable load in use, sessions and observed delay. TOPSI works on route identification, route binding, update and deletion process based on the validation of adaptive QoS metrics, before the optimal route selection process between source and destination. This research work discusses on the survey and analyzes the performance of TOPSI and RBL schemes. The simulation test beds and scenario mapping are carried out using Cooja network simulator.

Keywords: *IoT, QoS, RBL, MQTT, RTS/CTS.*

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1.0 INTRODUCTION

Internet of Things (IoT) has increased attention among public and industry to interact with different types of devices. IoT network encapsulates on overall infrastructure which includes application of user defined as service, software modules and hardware which support on user's determination to support on information networks. The integrated physical things [1] can exchange data about the physical properties and information that they sense in their environment.

IoT-supportive systems are expected to provide knowledge from context aware environments [7] to an adequate non-expert user. IoT-based system support different environments as it delivers the need to consider and ability to address multiple heterogeneous devices [3]. Hence the major concern within developing an IoT-based system supports on mechanism to handle interaction with the heterogeneous devices. IoT technologies allow multiple things or devices defined as objects to act / interact smartly and decide on collaborative decisions which are beneficial to critical applications.

The aim of this research work focuses on:

[1] To propose an optimized protocol design over IoT networks which need to improve reliability, as well as to reduce delivery delay time and the number of packet retransmission.

[2] To predict, analyze and provide optimal QoS approach in cases when the node density is less, or when nodes are out of range of communication.

The performance of TOPSI can be worked on a testbed which provide an avenue for a flexible experimentation system which is capable of reacting to dynamic changes of network conditions. TOPSI approach employs a network simulator tool Cooja to achieve the IoT network performance information which is dependent on the historical data of a physical testbed. The realistic QoS prediction of network performance is understood based on analysis and support for proposed physical network. This paper discusses on preliminary experiences of implementing an organization for encouraging QoS over IoT.

The problem statement defines the motivation behind providing QoS over “limited” mobile / wireless interconnected heterogeneous devices on varying location for deployment of multiple services in different networks. The research challenge incorporates the architecture being proposed scheduling module, which enable on the implementation of application deployment to network resources, using distributed and coordinated negotiation among network objects.

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1.1 IOT NETWORK – COMMUNICATION MODEL

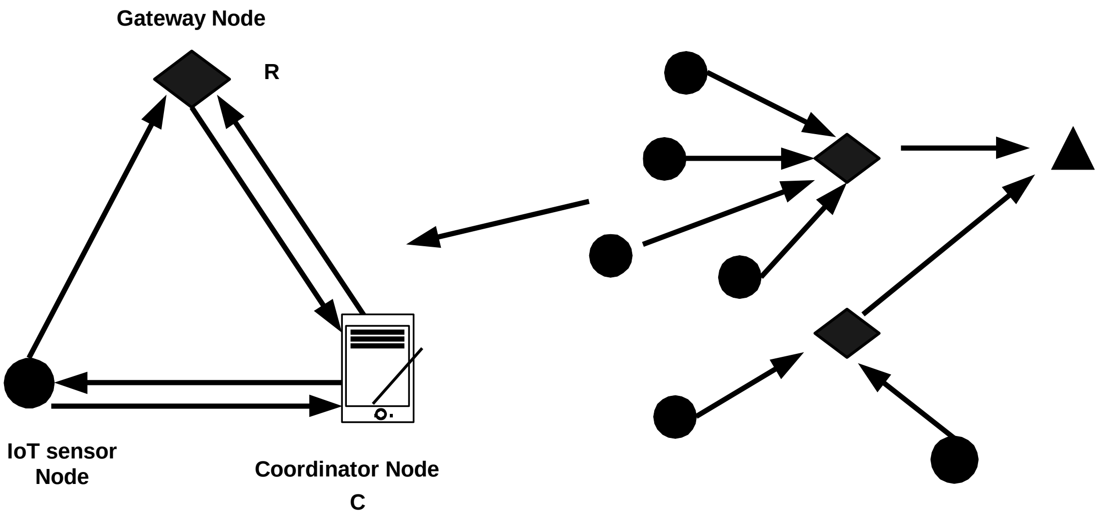

Fig. 1 IoT Network with Co-ordinator and Relay Nodes engaged in Communication

Fig. 1 shows multiple sensor nodes engaged in communication over a structured wireless inter connectivity. Each node sends its identity and broadcasts its identity to neighbour nodes (Hello protocol) to interconnect and communicate intermittently [8]. Each node communicates with neighbour node using the Gateway node (R) and Coordinator node (C). The Gateway node or Relay node R gathers all packets broadcasted from nodes, observes the identity and interconnects through the Coordinator Node 'C'. C determines the domain of interconnection for communication to be established optimally to support on QoS.

(a). IoT node Deployment : Multiple interconnected sensor nodes with pre-programmed functionalities support on aspects of network initialization whose phase includes addresses allocation, assignment of roles in network[7], synchronization and schedules to be determined[6].

(b). Association and disassociation of nodes: Nodes join or leave the network at random frequency intervals after the initialization phase. The defined routing protocol should handle situations where a malfunctioning node may affect or jeopardize the overall routing efficiency.

(c). Parameter constrained routing: Defined protocol should advertise node capabilities (CPU, memory size, available battery level) such as HELLO protocols [1] such that it supports on routing decision making. Any field node dynamically computes, select, and install different paths toward the same destination, depending on the nature of service traffic.

1.2 ROUTING PROTOCOLS AND THEIR CLASSIFICATION

The IoT routing protocols are used to establish a communication between nodes and exchange the messages with less overhead and computational burden with the support of routing information. Routing nodes and their attributes are essential in determining the overall performance of IoT. Each node in an IoT maintains routing information that assists the routing process, but the existence of uncertainty in network topology and vagueness in routing information may affect the performance of the IoT. The overall performance of the IoT can be improved, if the routing path is selected considering the routing attributes or nodes behaviours[5]. Therefore, it is essential to obtain knowledge about the routing nodes. The routing information of each node represents the knowledge about the routing nodes and it is often presented in a table in which columns are labeled by routing attributes whereas rows are labeled by nodes. The nodes in an IoT cannot be uniquely identified due to their behaviors or lack of sufficient information. Hence, adequate details of routing information are required to find the perfect knowledge about the routing nodes.

IoT supports three layer network as Data Link layer, Network layer comprising of both Routing and Encapsulation components and its protocols such as RPL, CORPL, CARP[10], and Session layer which supports MQTT, SMQTT, CoRE XMPP protocols[15]. Hence, to support effective data transfer and provide communication abilities, QoS among data transfer for specific service is required, which is the primary motivation of this research work.

1.3 QOS METRIC MODELING

a) Network Lifetime [14]

Route session time, which defines stability period of network, total network lifetime are considered as primary QoS metrics of network whose energy depletion is also a major concern. The time duration of network of all IoT active sensors considered as N and each node is initially equipped with traffic load L. The main objective of IoT supports on maximizing network lifetime T, which can be defined as linear programing approach:

Objective: $Max\ T=\sum rtr$ (1)

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where r and *tr* denotes the current round and summation of rounds observed over IoT sensor nodes.

b) Network Throughput [1]

Network throughput is defined as total number of successfully received packet information at the Coordinator C. The objectives support on maximizing chances of number of successful transmission of packets observed at Coordinator node C. The optimization expression for maximizing the number of successfully received packets *Pr*

Objective: $Max\sum rPr, \forall r\in T$ (2)
Subject to:
$P_S R > P_R C, \forall S\in N, \forall R\in N$ *(2a)*
$Bi \geq BTx\_min$ *(2b)*
$Plink \geq Pmin$ *(2c)*

The objective function (2) aims to maximize the number of successfully received packets *Pr* during the network lifetime T. Constraint (2a) demonstrates that data packets may drop when data transmission occurs from R to C. Constraint (2b) suggests that no data information transmission is possible when the residual buffer *Bi* is lower than the minimal required transmission B*Tx_min* as mentioned in (2b). (2c) states that the probability of a transmission link *Plink* should be no less than the minimal predetermined required value *Pmin*.

c). Delay [2][6]

End-to-end delay maximizes on the network lifetime or session in use which minimizes any increase in the delay over defined session. IoT network session links suffer from high energy attention leading to transmission link instability causing higher data transmission delay. Propagation delay is an important factor in dealing with high data rate transmission scenarios. The mathematical model of the end-to-end delay can be expressed as:

Objective: $Min\ \tau SC = \tau S + \tau TC$(3)

Where τSC represents delay for IoT sensor node, which S transmits to the central coordinator C.
τS and τTCrepresent nodal delay at S and delay for data transmission between R and C, respectively.

Subject to:

$\tau S \geq \tau TxS + \tau QU + \tau DPS + \tau CCP, \forall S\in N$ (4)
$x \geq N \geq 0, \forall x\in Z+PSR \geq PS$
$\gamma depS \geq \gamma arrS$
$BERi \geq BERpre$

$Min\ dSR \rightarrow dmin$

Constraint (4) illustrates that the nodal delay τS, *which* consists of the propagation delay τTxS, queuing delay τQU, data processing delay τDPS and channel capture delay as τCCP [4]. This constraint defines BER as Bit Error ratio observed during transmission of data.

A deterministic approach to reduce the propagation delay τTxS, to minimize the transmission distance is defined as:
$\tau TxS = d(S)/s$ (5)
where $d(S)$, denotes the distance between the IoT sensor node to Gateway R for every iteration and s is the speed of electromagnetic wave.

2.0 LITERATURE REVIEW

Recent literature survey on task scheduling and supporting on QoS towards pre-processing for IoT sensory applications is studied. Author [13] focuses towards service latency and energy consumption of the new Fog paradigm being evaluated and applied to IoT. The work is also compared to traditional Cloud scenarios. The model [7] deals with behaviour of IoT modules deployed over Fog infrastructures.

Sharief[10] defines pruned resource scheduling for adaptive routing over IoT infrastructure which demands Quality of Information (QoI) of sensor nodes linked on task relevancy being proposed towards measurement of the sensing capabilities of sensor nodes against the execution of QoS requirements tasks. OanaIova [12] suggests on multi-parent routing decision being defined at run time which is required to ensure on the fairness in distribution of tasks. The transition of Task is modeled using adaptive Discrete Time Markov Chain (DTMC) models which detect the incoming tasks in order to wake up sensor nodes.

TRAPS [9] in the gateway consists of a task pre-processor module (responsible for gathering the requirements of incoming tasks and further classifying the tasks based on their requirements), can be defines as EMS module (for monitoring the control of data packets over sensor nodes) and a scheduler module (to schedule the tasks).

Sourabh Bharti [11] defines a cross layer solution for QoS based scheduling of packets which argues that QoS management in IoT is still yet to be supported on lossy networks [8] and the demand for new service supported QoS attributes are demanded which requires energy consumption, information accuracy, coverage for IoT sensory environments. It primarily supports on decision making processes for QoS proposed at each layer.

Winter et al [14] defines RPL protocol as rank of nodes being computed based on DAG's Objective Function (OF). This protocol supports on effective QoS towards lossy networks on low powered communication devices. It defines usage of routing metrics, sets the optimization objectives, and optimistic functions to compute node rank. The RPL topology is built using control messages which are transmitted as ICMPv6 messages.

3.0 TOPSI – MODELLING APPROACH

A N-state threshold based queuing system is considered. The traffic intensity level will be governed by the forward threshold vector F= (K_{t1}, K_{t2} …….) and a reverse threshold vector R= (K_{r1}, K_{r2} …..). The behavior of

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this system is as follows: if the packets arriving the empty system at the rate of λ can serviced at the rate of μ at first traffic intensity level. If the packets arriving a system, cross the threshold value K_t then it will enter into the next traffic intensity level. If the packets has been serviced and falls below K_r, the system moves to a state before traffic intensity level. Fig. 2 shows the state transition diagram. N state queuing system is considered and M is the corresponding Markov process with state space M.

M = {K, S, I}, where K is the number of packets, S is the network condition or channel state, I is the level of traffic intensity

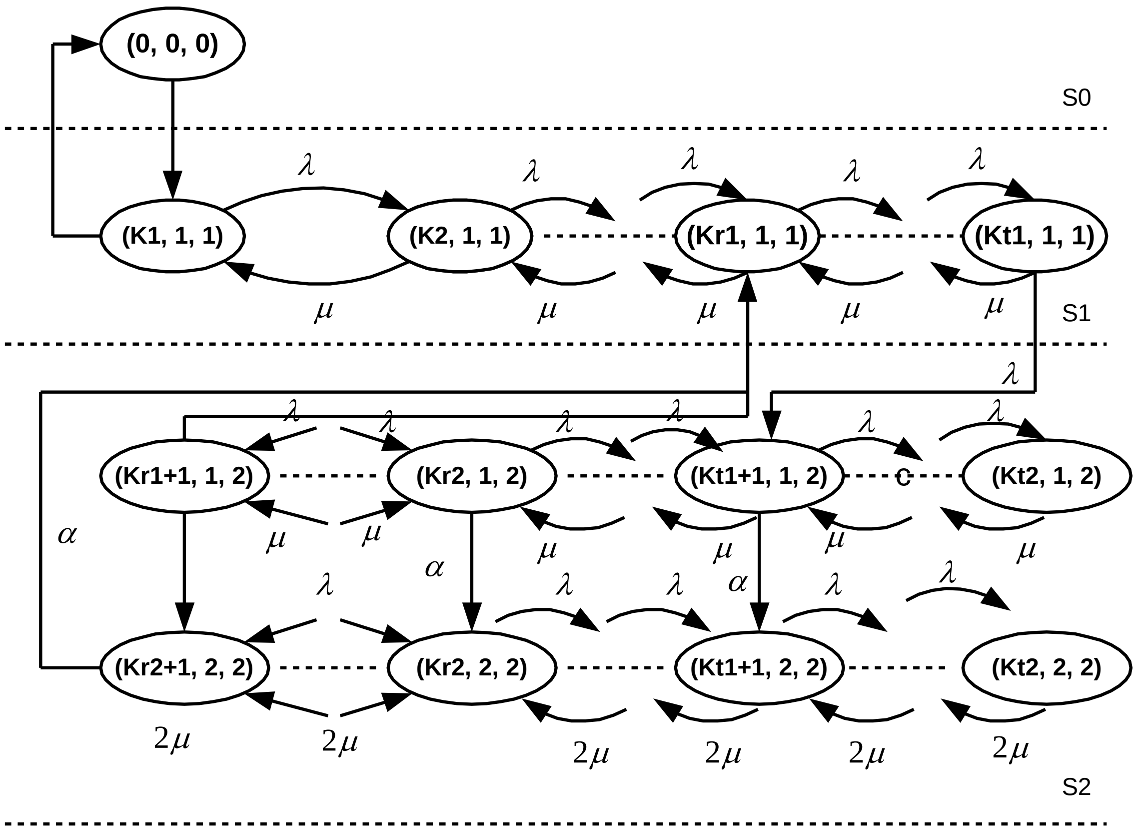

Fig.2 State Transition diagram for 1=2

The channel state S have different parameters like number of active nodes, number of groups, routes available, and session time. Using these parameters the available bandwidth in that state can be estimated. By knowing traffic intensity level, one can decide how many applications can be run in that particular state at that instant. Formally, the transition diagram of the above Markov model with N state spaces can be defined as follows:

$(0, 0, 0) \longrightarrow (K1, 1,1)$ with rate λ

$(i, j, l) \longrightarrow (i+1, j, l+1)$ with rate $\lambda 1\{(i = Kt \in K) \wedge (l = I) \}$

$(i, j, l) \longrightarrow (i+1, j, l)$ with rate $\lambda 1 \{ (i \neq K) \vee (i = Kt \in K) \wedge (l \neq I)\}$

$(i, j, l) \longrightarrow (i, j+1, l)$with rate $(l – j)$ ά1 $\{ (l – j) > 0\}$

$(i, j, l) \longrightarrow (i-1, \min(j, l-1), l-1)$, with rate $j\ \mu 1\{ (i-1 = Kr \in K) \wedge (l = I+1)\}$

$(i, j, l) \longrightarrow (i-1, j, l)$, with rate $j\ \mu 1\{ (i >=-1(i-1, j, l) \neq (1, 1, 1)) \wedge ((I -1 \notin K) \vee (I - 1 \neq Kr \in K) \wedge ((l \neq I+1))\}$

$(1, 1, 1) \longrightarrow (0, 0, 0)$ with rate μ

Here ά is the rate at which the traffic will be increasing. 1{x} is the indicator function i.e. its value is equal to 1 if the condition is true and its value is zero otherwise. The aggregated state transition diagram of the above Markov model is suggested in Fig. 3.

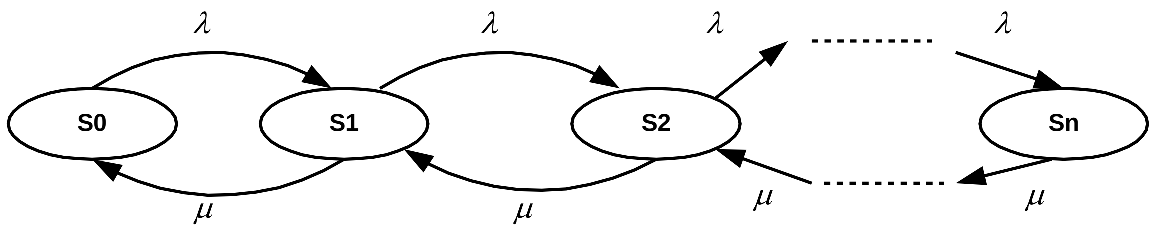

Fig. 3 Aggregated state transition Diagram for n states

Let $P_{ij}=P_r\{X_n = j/X_n-1 = i\}$ be the single step transition probability.

Let $P_{ij}^{(m)}$be the m – step transition probability.

$P_{ij}^{(m)}= \sum_r P_{ir}^{(m-k)}P_{ij}^{(k)}$

Let $\Pi_j^{(n)}$ be the unconditional probability of state j at the n^{th} trial.

Let $\Pi_j^{(n)} = P_r\{ X_n = j \}$, $P^{(m)} = P^{(m-k)}\ P^{(k)}$

Let $k = m-1$; $P^{(m)} = P\ .P^{(m-1)}$

On continuous submission of m= m-2, m-3 ……,

$P^{(m)} = P.\ P.\ P\ldots\ldots\ldots\ldots\ldots P\ .\ P^m$

$\Pi^{(m)} = P^{(m-1)}\cdot P,\ \Pi^{(m)} = \Pi^{(0)}\ .\ P^m$

Where $\Pi^{(0)}$ is the initial state vector.

Let $Q = P – I$ then, $P^{(m)}\cdot\Pi^{(m-1)} = \Pi^{(m-1)}\ .\ Q$, where P is always a stochastic matrix and Q has rows that sum to zero.

Let N be the number of states and let $P_{ij}^{(m)}$be the probability transition matrix. Let $D_{ij}^{(m)}$be the delay matrix which determines the delay in each state, while $f_n(i)$ be the optimal expected delay of the system in a particular state n.

Let M= $\{S_1, S_2\ \ldots\ldots\}$be the set of states and A= $\{a_1,a_2\ \ldots\ldots)$ be the set of actions. Also let k be the available policies i.e. each policy will generate a different action that changes the state of the system. The backward recursive equation relating f_n and f_{n+1} is

$f_n(i) = \min_k \{ \sum_{j=1}^{m} P_{ij}^{k}\ [D_{ij}^{k} + f_{n+1}(j)]\}$, n=1, 2, …….,N, where $f_{n+1}(j) = 0$ for all j.

Let $V_i^k = \sum_{j=1}^{m} P_{ij}^{k} D_{ij}^{k}$

Let ά (<1) be the rate of increase in traffic intensity. Also $f_n(i) = \min_k \{ V_i^k \}$

$f_n(i) = \min_k \{V_i^k + ά \sum_{j=1}^{m} P_{ij}^{k}\ f_{n+1}(j)$, where n = 1, 2, ….., N-1.

By using the above equations, the optimum policy that can provide an optimum QoS to the application at that instant can be identified.

If nodes in one domain need to communicate with nodes in another domain then the domain head (Coordinator) establishes a path with the help of another cluster domain head. Even though cluster head may add delay in between a communication path, but still this protocol creates minimal flooding packets in network and hence reduce delay in round trip time. TOPSI scheme works as a hybrid reactive protocol in its behavior, such that its component modules are activated initially when the service is invoked but the module exhibits its behavior only when the session is in use. Hence when modules are invoked, the process is not triggered, but when the session is put into use, the components get activated.

The TOPSI architecture adopts the following functionality of Mobile node on as-is-basis:

a).When a new node (n) wishes to join a domain, then node n, needs to send a register message to Coordinator Node(C), which in turn may send a reply message to join the domain. A node, which has to cater various types of services, sends REQ (Route Request) message with service type to C for establishment of new route. C sends REP (Route Reply) to nodes, which should function as source, destination and hand-off. If any node in the domain misses its neighbor for route update and communication then it send ERR (error) message to C. Every node sends its set of QoS parameter to C at frequent time intervals.

b). Similar to new node (n) joining the domain cluster, any node (m) can quit or re-join the domain at a time, as the nodes are consistently on mobility.

c.) TOPSI QoS reservation manager consistently updates the QoS parameter(s) of all its registered nodes.

Each node must detect the neighbor nodes with which it has a direct link. For this, each node periodically broadcasts *Hello messages* [8], containing the list of neighbors known to the node and their link status.

The link status can be either symmetric (if communication is possible in both directions), or asymmetric (if communication is only possible in one direction). The *Hello messages* are received by all one-hop neighbors, but are not forwarded. They are broadcasted once, per refreshing period, called *Hello interval* by 25 to 50 ms. Thus, *Hello* advertisement messages enable each node to discover its one-hop neighbors, as well as its two-hop neighbors. This neighborhood and two-hop neighborhood information has an associated holding time, after which it is no longer valid and to be refreshed.

4. TOPSI ROUTING PROCEDURE

With hybrid reactive protocols, each node maintains the routes to all other nodes in the network by periodic exchange of control messages. When a node needs to send a

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packet to any other node in the network, the route is immediately available. The main advantage of hybrid reactive protocols is that they do not introduce a delay before sending data, but determines multiple paths for routing. Furthermore, these protocols are useful for traffic patterns where large subsets of nodes are communicating with another large subset of nodes, and where the source and destination pairs are changing over time. The route implementation in the platform adopts a hysteresis mechanism, based on received power measurements:

a. Before a link to another node is accepted, the receive power of the corresponding neighbour node must be above a threshold, which is set to -85 dBm in experiments.

b. As long as it is above a (lower) threshold, here equal to -94 dBm, and it is correctly refreshed, the link is considered to be valid.

In the presence of topological changes like node appearance, disappearance and node mobility, the protocol TOPSI, detects these changes and updates the routes accordingly, in order to maintain the shortest route to any destination in the network. The measurements concerning the bandwidth are collected at regular intervals of time. The model considers TCP flows and measure the bandwidth obtained at the destination node. The experiment duration is 60 seconds based on initial tests ranging from 10 to 180 seconds (whereas 60 seconds is found enough for obtaining reproducible results). The influence of different parameters such as the presence of other traffics (at the source, at the destination or more generally in the network), the use of the RTS/CTS observed to spatial reuse is studied.

In Fig. 4, the node-1 identified as source ‘S’ in domain-A, needs to communicate on stream data to node-7 identified as receiver ‘D’, so it sends a route request message (Req) to domain controller ‘C’, where C identifies its domain node information, and finds an appropriate path. Once the path is found, it sends a Transmit (Tran) message to ‘S’ and Receive (Recv) message to ‘D’. Transmit and receive messages contains route information and port numbers.

The node-8 in domain-B, needs to stream to node-3, hence the route request message (Req) is send to domain controller-B. The domain controller-B understands its domain node information, and updates the path. Once the path is identified then the data Transmit (Tran) message is sent to node-5, supports on alternate route message to node-4 and Receive (Recv) message to node-3. Transmit, alternate route message and receive message contains route information and port numbers.

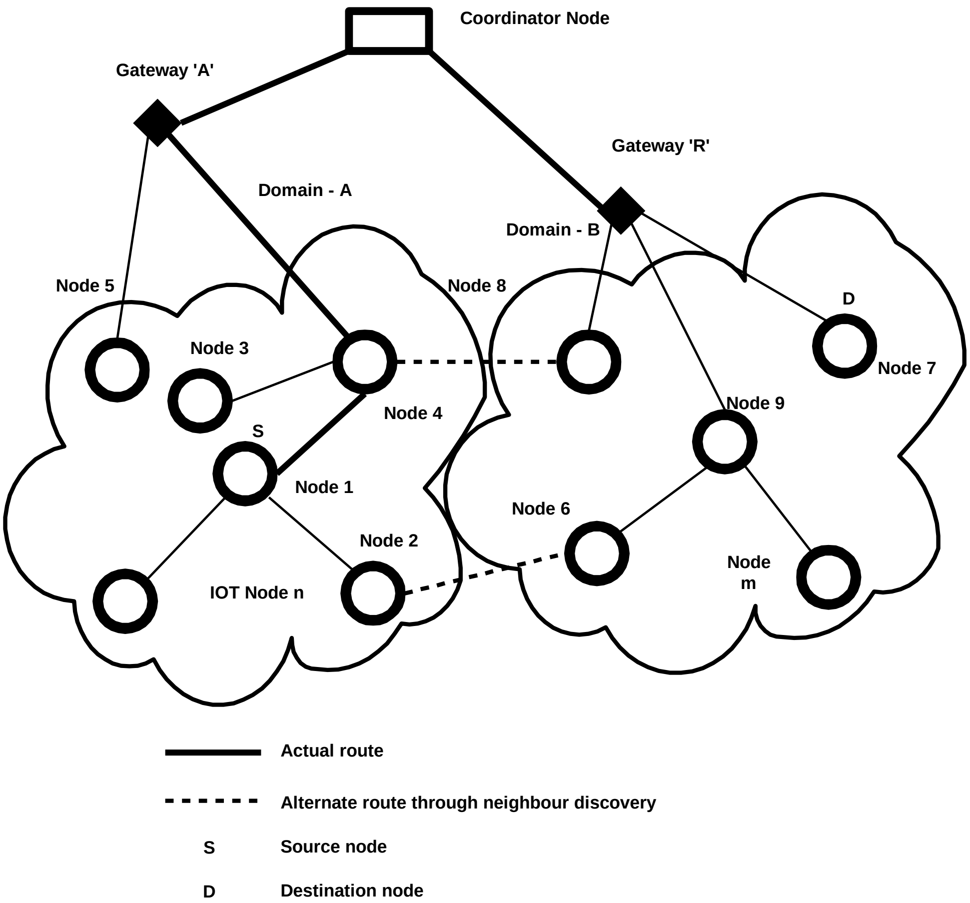

Fig. 4 Inter Domain communication of IoT Nodes

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Definitions:

rBwd – required bandwidth observed by Service Discovery Manager

rPdr - packet delivery ratio

rBwl – Available Bandwidth

rPlp - Packet Loss

rDelay – Round Trip Delay

Vector NodeList [ ] – Number of IoT Nodes

Vector RouteList [ ] –Number of Routes

1: Determine node location and Update Configuration

Vector NodeList [ ] = Add_Node (Node.Location, Node. Config)

2: Check Node.Status( )

If (Node.Status = ACTIVE &Node.Type = ALTERNATE) THEN
{
Update_QoS ($Node_i$, $Node_j$, $Node_{k,..n-1}$, rBwd, rPlp, rDelay)
Set $Node_{i.n}$ = Node.Neighbour
Add_Node ($Node_{i..n}$)
}
If (Node.Status = IDLE or Node.Status = NOI) // Not In use
Remove_Node ($Node_{i..n}$)

3: Check and Update Neighbour

If ($Node_i$Is.NeighbourNode$_{j..n}$) then

Add_Node ($Node_{j..n}$) // attach as neighbor

If ($Node_i$.Is.rBwd OR Is.rPlp OR Is.rDelay) then

Add_Node($Node_i$) // attach as acceptable QoS

4: Define Route

If (! Route.Status = EXISTS)
Vector RouteList[ ] = Add_Route ($Route_a$)
Else
Create_Route (Route I, NodeList [ ] &Node.Status=ACTIVE)
If (! path.Status = ($Node_i$, $Node_j$))
ReEstablishSession( )
Else
{
Route_List = Add ($Node_i$, $Node_j$ …) →RouteList [ ] where 'a' to 'z' being possible routes defined
Create_Route ($Route_a$)
}

The algorithm TOPSI supports on aspects of Route Creation, adding a Node to existing domain, Node leaving the domain, as well as controlling the traffic intensity at gateways. The Route List maintains the number of IoT nodes in active status at each domain and support of session life time in route until session is completed.

5.0 EXPERIMENTAL APPROACH

An early stage of testing the organization for absorbing the system behavior and reacting with necessary actuation to the WSN reconfiguration has shown encouraging results. The simulated test-bed works on Cooja simulator [1] which runs on Contiki-OS. The experiment supports on simulation of 100 IoT nodes defined as Mote shown in Fig. 5 whose property is defined in Table 1.

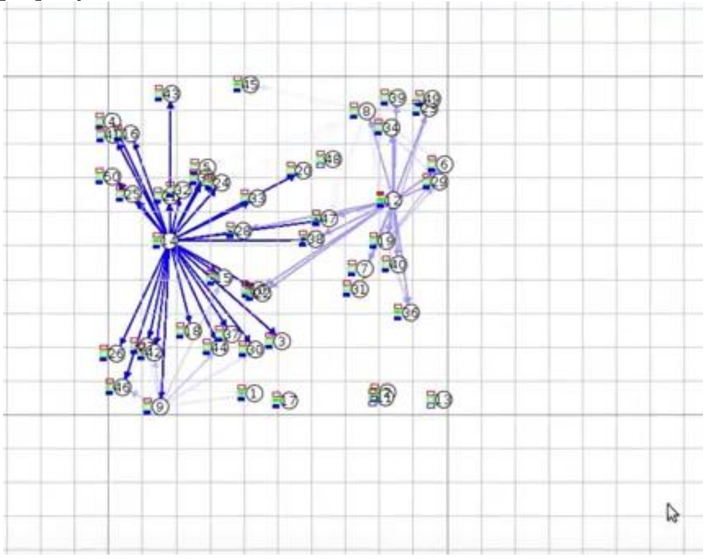

Fig. 5 Simulation test-bed over 100 nodes

Attributes	Values
Number of Nodes	100
Simulation time (secs)	3600 secs
Simulation Area	500 x 500 m2
Simulator / MAC protocol	Cooja / CSMA
Mote Type / OS	Sky Mote / Contiki 2.7
Radio Medium	UDGRM (Unit Medium) : Distance Loss
Mote Start up delay (ms)	1000
Transmission range (m)	50

Table 1 Network properties for Mote

Mote nodes are placed randomly at random locations on simulator space, where the nodes can communicate with either nodes using neighbourhood property. Motes are under limited mobility or static based on the experimental setup adopted.

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6.0 PERFORMANCE ANALYSIS:

TOPSI performance analysis is observed based on variable QoS metrics such as Throughput, Packet Loss, and End-to-end delay. Fig. 6 shows the observed throughput of TOPSI over RPL routing scheme. TOPSI shows an average throughput of 138 Mbps compared to RPL which shows 40 Mbps. TOPSI shows an average throughput of 76.46 Mbps maintained throughout the session for varying node up to 100 nodes. The experiment shows that the throughput increases incrementally from 40 Mbps to 140 Mbps for variable services and nodes in use. Once the number of nodes is added after a period of time, throughput maintains its saturation level until it reaches a small increase in goodness received.

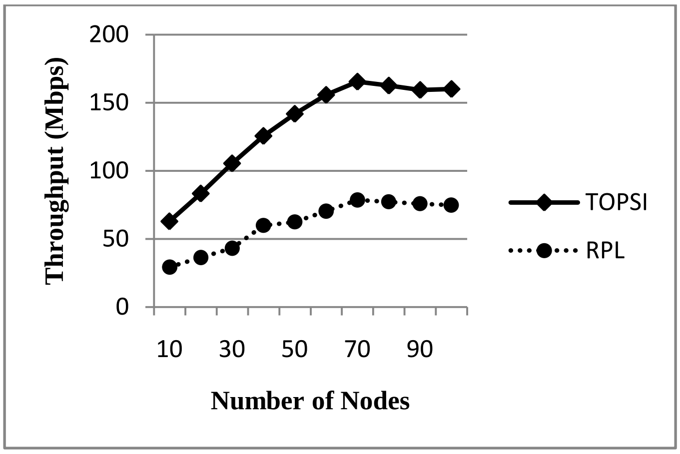

Fig. 6 Observed throughput over varying number of nodes

The packet delivery ratio is observed in Fig. 7, where performance of TOPSI is found to overcome RPL protocol routing approach in terms of number of packets delivered over traffic congested bandwidth at any instant of time. Packet Delivery Ratio depends on number of packets waiting at Gateway to be serviced as well as number of packets being received at receiver end. TOPSI shows 65.29 % of delivery ratio for variable number of nodes while RPL shows only 35.93 % of packet delivery as shown in Fig. 7.

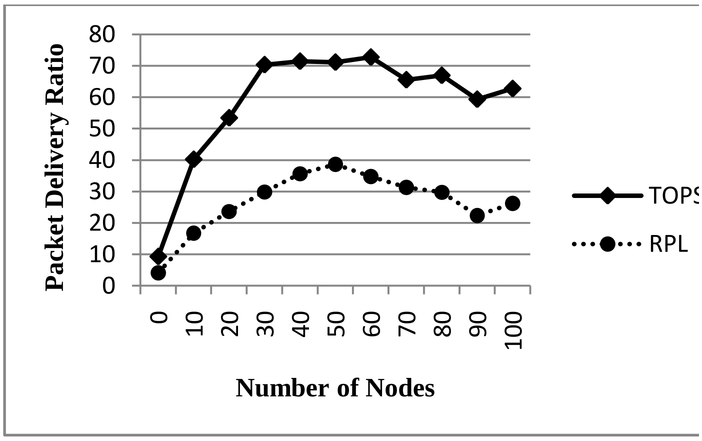

Fig. 7 Packet Delivery Ratio observed at Gateways over varying number of nodes

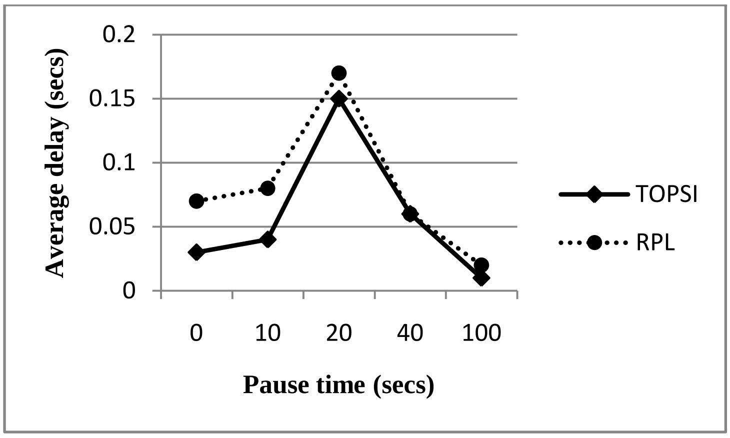

Fig. 8 Observed delay time

The observed waiting time for prioritized packets whose variable buffer size of 10, 15 and 20 is found to be similar. The observed queue waiting time for medium prioritized packets with varying buffer sizes to 100, 50, 20 differs on type of service. Average waiting time for sensor generated packets of variable priority of different buffer sizes is high for buffer size which is > 100 bps. The service packets are considered to be waiting in queue for high time when packets are of low priority packets. The waiting time depends on the variable size of the packets. If packet size is more, waiting time in the queue will increase because in that particular cycle it will be scheduled. The observed end to end delay of service is shown in Fig. 8. The average delay observed at TOPSI shows 0.09 seconds which actually performs better than RPL routing scheme.

7.0 CONCLUSION

IoT networks find major influence in industry for integrating various physical devices into information networks and supporting on day-to-day societal needs.

This paper discusses on proposed TOPSI domain based relaying strategy whose performance is compared with RPL and the two-relay protocol. Performance analysis and its results show that TOPSI adopts domain based relaying routing protocol which outperforms the two-relay based protocol in terms of throughput, PDR and End-to-End delay. TOPSI also supports optimal routing with high traffic load conditions and minimal round trip delay.

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