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TOPQoS : TENSOR Based Optimum Path Selection in Internet of Things to Enhance Quality of Service

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ABSTRACT

The electronic devices or gadgets that are connected to the internet play a prominent role among human beings in this new era. The things connected together bring smartness to the network. The smart Network of the things or objects is termed as Internet of Things (IoT). IoT acts as a bridge between the Internet world and the real world. It changes the ordinary devices into smart devices by adding intelligence to the system which is connected to the Internet. The routing protocol for IoT needs to satisfy the applications needed for lossy sensor nodes. In this paper, the Light weight On-demand Ad-hoc Distance Vector routing protocol – Next Generation (LOADng) is enhanced to achieve QoS by optimum path selection. The proposed Tensor Based Optimum Path (TOP) identification technique dynamically identifies optimum path Using TENSOR model. The proposed work is implemented using cooja IoT simulator.

Keywords : Internet of Things, Quality of Service, Smart home, PDR, Packet Loss, Timeliness Contiki.

I. INTRODUCTION

IoT network can be divided into upper layer, middle layer and lower layer namely IP Network Middleware IPv6 over Networks of Resource-constrained Nodes (6Lo) and Low power Lossy Network (LLN). The characteristic of network varies from application to application [1]. Smart connectivity with existing networks and context-aware computation using network resources are indispensable part of IoT [2,3]. IoT has huge potential for developing more creative applications in many fields [4]. There are so many IoT applications existing such as smart city [5], smart home [6], smart healthcare [7], agriculture and breeding [8], augmented maps [9], assisted driving etc. Some applications involving IoT technologies are shown in figure 1.

The QoS parameters for IoT applications are different from network quality of services [10]. The traditional routing identifies optimum path with various parameters such as delay aware path, energy aware path etc., The IoT Applications required typical optimum path with delay sensitive, energy optimized, trusted path and reliable path for achiving quality. The proposed work identifies optimum path towards destination using unified five-order Tensor model. It refers to a periodic transfer of data. It is mainly used for sensors, actuators or other devices that require low power consumption. The remaining paper is organized as follows; Section II presents IoT related works. Section III explains the proposed work, with figures and tables. Section IV illustrates Smart home case study and finally Section V gives simulation results followed by section VI concludes the work.

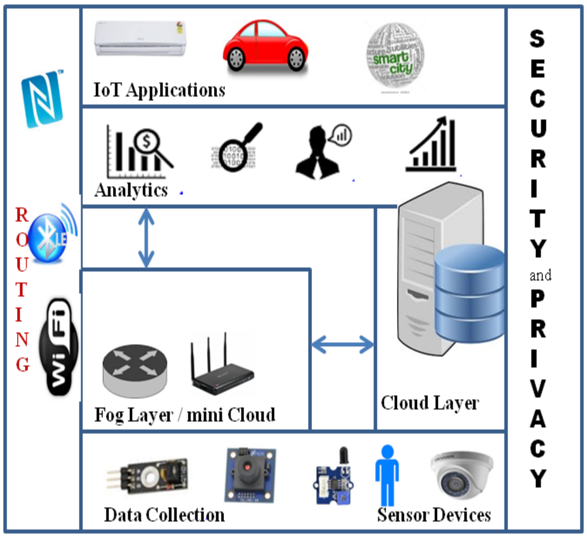

Figure 1. IoT Layers and Technologies

II. REVIEW OF LITERATURE

Routing is the process of identifying optimum path from source to destination. Routing includes various parameters like delay, bandwidth, energy, etc. Routing in IoT can be classified into flat routing, hierarchical routing, and location based routing. The performance of routing protocol is measured in terms of QoS parameters [11]. Routing Protocol for Low power Lossy Network (RPL) is a proactive routing protocol. RPL classifies the network into storing mode and non storing mode. In a non storing mode, the root node alone is aware of the network information (ie children and parent information) whereas in storing mode all parent nodes are aware of their parent and child nodes. In RPL, a DODAG is created with sink node as a root. The data transmission may follow upward traffic (ie towards the root) or downwards traffic (ie towards leaf node) or both [12]. The path selection in RPL is based on the link metric and path metric type. Based on these metric values, the link is classified as weak links and strong links. The paths with minimum weak links are identified as optimum path. The default metrics in RPL are hop count and Expected Transmission count (ETX). Due to the heterogeneity nature of the IoT application, minimum hop paths are not always the optimum path. Santiago et al [13], proposed energy based optimum path selection in RPL. The authors used transmission range property of the node to identify the preferred parent.

Low power Ad-Hoc Distance Vector Routing next generation (LOADng) is a reactive protocol [14]. It is derived from AODV protocol compromising many features of AODV to attain the light weight nature. The path between the source and destination is identified dynamically. LOADng router uses three types of control packets RREQ, RREP and RERR. The RREQ and RREP are used to identify the available paths between the sender and the receiver. The RRER is used for route maintenance. The default path parameter in LOADNng protocol is hop count [15].

The Hop count metric is modified in Distributed QoS aware Meta routing [16]. The Qos (Quality of Service) parameters considered by the author are timeliness and reliability. Dalvin vinoth kumar et al., [17] proposed a routing technique for reducing control packets to enhance the quality of service. The author has concentrated on route discovery overhead to improve the Quality of service. Arockiam et al., [18] proposed a technique to enhance LOAD protocol to improve the Quality of service in IoT routing. Vithya et al., [19] proposed a dynamic location predication technique to authenticate the user. The Received Signal Strength (RRSI) is used as a key parameter to find the location of the node. The review of Bill et al., [20] classified the transmission strategy into three categories such as unicast, geocast, and multicast. Internet of Vehicle routing is carried-out using Wimax for LAN and LTE for internet connection. The Road Side Unit (RSU) and vehicles are connected in LAN and RSU is connected to the cloud using LTE network. The routing QoS is achieved by considering various metrics as shown in table 1.

Table 1. QoS parameters in IoT

S.No	Author	Network	QoS parameter
1	Sean Dieter Tebje Kelly [21]	IoT	Reliability
2	Mengchu Zhou [22]	WSN/IoT	Energy, control packet
3	Machado [23]	IoT	Energy, Link Quality
4	Chong Han [24]	IoT	Delay, Energy
5	Oladayo Bello [25]	D to D, IoT	Mobility

III. Tensor based Optimum Path Selection (TOBP) Model

The Tensor model (T) is used in quasi-LPV (q-LPV) control theory to transform the transition function F(t). TENSOR model is used to identify center of the plane. The center of plane and parameters in a plane are linear functions. The number of centers increases when the number of parameters increases. Figure 2 shows two different center points for a same plane. The plane with two parameters X and Y respectively gives a center of plane at position P1 and the same plane with three different parameters X, Y and Z respectively gives a center of plane at position p2. . The proposed work Tensor Based Optimum path (TBOP) optimizes the optimum path identification process using Tensor Transition model. TBOP uses five-order Tensor model, where overall delay I_d of path R, available energy I_E, the mobility I_M, Trust factor I_T and available Bandwidth I_b are given as the input vector function for tensor transition model to compute the tensor element te as given in equation 1. Figure 3 shows the five order tensor transition model and subsequently the TBOR algorithm is explained

Tensor Element (te) $\in I_d * I_E * I_M * I_T * I_b$ (1)

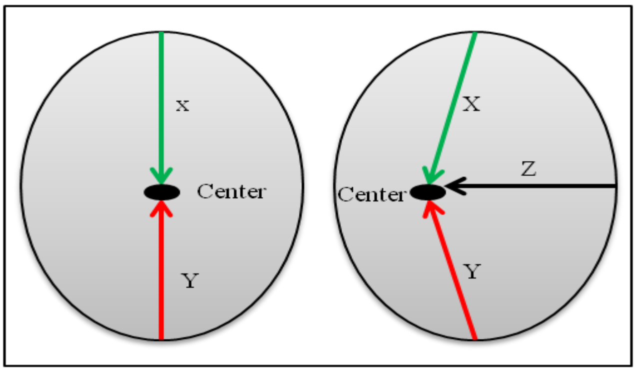

Figure 2. TENSOR Model

The working procedure of path selection is as follows

Algorithm 1. Optimum Path Identification

Input: parameters of a path
Process: Optimum path identification
Output: Best Path
Procedure TBOP (I_d, I_E, I_M, I_T, I_b)
Rte ← shortest path (O, S)
if *f te* (*Rte*) ≤ Δ*D* **then return** *Rte*
else *op* ← shortest path (*O*, *S*)
if *fop* (*Rte*) > Δ*D* **then return** "No optimum Path Available."
else
while *true* **do**
λ ← (*fte* (*te*) –*fte* (*op*)) / (*fop*(*op*) –*fop*(*te*))
R ← SHORTEST PATH (*G, s, t, cλ*)
if *fλ* (*R*) = *fλ* (*Rte*) **then return** *op*
else if *fop*(*R*) ≤ Δ*D* **then** *op* ← *R*
else *Rte* ← *R*
end if
end while
end if
end if
end procedure

Algorithm 2 Route Discovery Process with Max.Hop.Count=4

Input: Sender(S), Receiver/ Destination (D)
Output: Optimum path to Destination
Procedure Route Discovery
{
* source node having Active path to Destination *\
If (Destination node is one hop neighbor to the source)
{ *Initiate data transfer*\ }
Else If
{ CALL PREQ *Construct the PREQ and broadcast to its neighbors*\
SN i receives RREQ and process the RREQ\
If (PREQ.packet is Valid = True)
{
Do for all neighbours until TTL expires
{
Until N.add = RREQ.Destination
}
} **end if**
If (N.add is RREQ.Destination = True)
{
CONSTRUCT RREP (S, D) *Forward Route*\
{RREP.add_length ;
RREP. Seq_ Number;
Hop count ;
Hop limit ;
RREP. Destination = source device address;
RREP . Orginator = destination device address;
RREP.hop_limit = max_hoplimit;
RREP metricType
RREP _ route metric
If addr_length in Received RREP ≠ Addr_ length of the receiver device
{
If addr in the message . orginator ≠ addr of the receiver device
{
If (hop_count < max_hopcount)
{
If (hop_limit ≠ 0)
{
Set variable hop count =msg .Hopcount +1; *Process the received RREP*\
Variable hop_limit = msg .hopcount -1 ;
* enter the values for mutable fields in PREP*\
PREP. metric type , PREP route metric
PREP.ack.required, PREP.hop_limit , PREP.hop_count
Unicast the PREP to the identical nodes
Create forward route towards the destination
} **end if**
The Packet is Invalid
} **end if**
Drop the Packet
} **end if**
Increase the TTL and Restart the Route Discovery
} **end if**
Not a valid packet
} **end if**
Path not Available
} **end if**
TOPQoS (available path set p_i)
Stop Procedure

The network topology is represented as N (O, S), where n is a set of nodes, O is the Originator (Source), S is the sink node (destination) and P is a set of paths. R (o, s) represents a set of all routes between source node (o) and destination node (s). The proposed Tensor Based Optimum path (TBOP) is to minimize path delay function $fRte$ (R) of routing path R. where fop (R) is the function to calculate optimum path using the overall delay of R, Optimum path (O) is the path with minimum delay, maximum available energy E, high reliability, trusted path and maximum Bandwidth. Reliability of link is computed by mobility factor of nodes in the path. The trust factor t depends on packet delivery ratio and the open path loss p. SHORTEST PATH () algorithm is used to find the path function as shown in the equation 2 [20]. SHORTEST PATH () algorithm finds the shortest path (Rte) based on Tensor input vector functions. If the path R identified by SHORTEST PATH ( ) algorithm satisfies the optimum path threshold then the path R is the optimum path else the next path R+1 is investigated using SHORTEST PATH ( ).

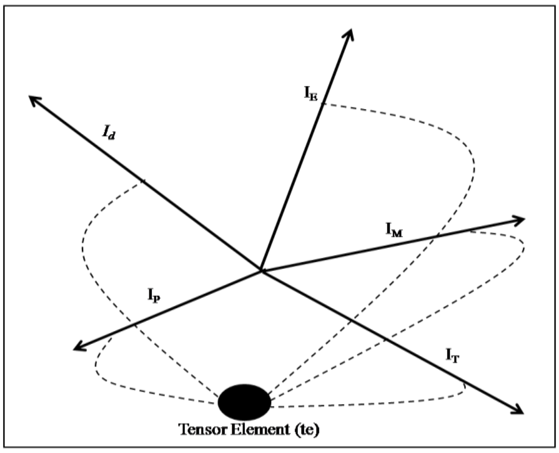

Figure 3. Five order Tensor Model

$$\min \{ fte(R) \mid R \in R(O,S), fOp(R) \leq \Delta D \} \quad (2)$$

IV. SMART HOME CASE STUDY

Smart Home is refers to the control and automation of home appliances, household features as shown in Figure 4. It enables Anything Anywhere and Anytime control of devices. The sensors are used to sense environment and actuators used to control environment. The communication technologies like Bluetooth, Wifi, zigbee, Z-wave, LoraWan, etc are used to establish local area network between devices and gateway. The Gateway enables a direct link to Internet through Mobile Network, LTE, WiMax, etc.

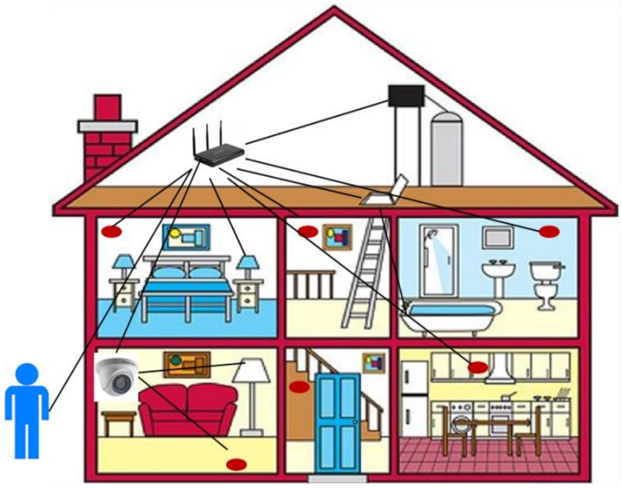

Figure 4. IoT Based Smart Home

In the above smart Home Scenario the user requesting a data from Refrigerator. User is the source node and refrigerator is the destination and some other nodes act as intermediate nodes to establish the communication as shown in the figure 5. The delay between nodes and available energy, and mobility of the node are given in table 2. The traditional routing protocols identify various optimum paths based on the application requirement. The link between devices is given in matrix. If a direct link is available then its value is 1 otherwise, its value is 0. The delay aware path is the path with low transmission delay (1-3-6-7). The hop count aware path is one with least intermediate nodes (1-4-7). The energy aware path is the path with maximum available energy (1-2-5-7). The proposed TORB algorithm identifies optimum path using 5- Order TENSOR model. The five parameters delay, energy, mobility, trust and bandwidth are used to identify optimum path.

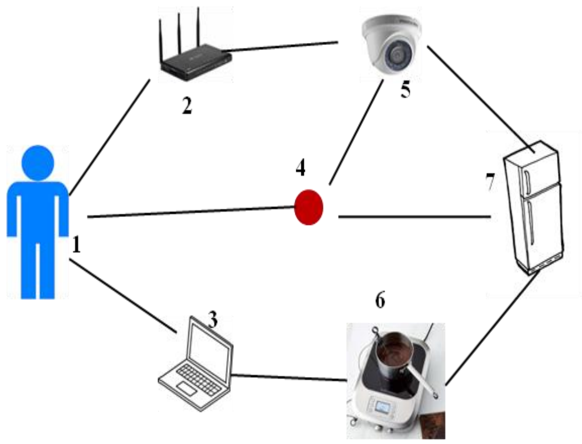

Figure 5. Network Topology

$$\begin{bmatrix} Node & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\ 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 2 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 3 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 4 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 5 & 0 & 1 & 0 & 1 & 0 & 0 & 1 \\ 6 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 7 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \end{bmatrix}$$

Table 2. Routing Parameters

Link	Delay(ms)	Energy(J)	Mobility
1, 2	60	10	High
1,3	40	15	Medium
1,4	30	10	Low
2,5	90	20	Low
3,6	90	10	Low
4,5	70	10	Medium
4,7	90	20	High
5,7	70	10	Low
6,7	80	10	Medium

The matrix shows direct link between devices, the device 1 has direct link to devices 2, 3 and 4. So the value 1 is assigned to them. Nodes 5, 6, and 7 has no direct link hence, the value 0 assigned to them. The parent nodes consume more energy than children nodes. The simulation shows the importance of energy aware path. The table 3 gives various optimum paths for network topologies given in table 3. The proposed TOBP model identifies optimum with maximum number of parameters.

Table 3. Routing parameters vs Optimum path

Parameter	Path	Delay	Energy	Bandwidth	Mobility	Trust
Delay	1-3-6-7	yes	No	yes	No	No
Energy	1-2-5-7	yes	yes	yes	No	No
Hop count	1-4-7	No	No	No	No	No
TORB	1-4-5-7	Yes	yes	yes	yes	yes

V. SIMULATION

Cooja is IoT network simulator with contiki operating system environment. Contiki is an open source Operating System for constrained devices in IoT environment. In cooja, nodes are referred as motes. The simulation is carried out in 100 x 100 meter environment with 10 to 50 sensor nodes; 3 attacker nodes and 1 border router. Figure 6 shows the node arrangement inside network environment. The node parameter and Routing parameters used in simulation are tabulated in Table 4. The simulation is carried out using three different types of nodes.

Parameter	Value
Simulator	Cooja
Operating system	Contiki V2.5, ubuntu
Radio	CC1000, CC2420
Node Density	5 device \100 sqm
Number of Nodes	10, 20, 30, 40, 50
Range	50\85 (tr\ir)
Data packets	100 bytes
Metrics	0, 1 (hop count\TBOP)
Route Life Time	5 seconds
Net Traversal Time	2 seconds

The experiments are conducted with different types of network and routing environments to evaluate the proposed algorithm. The accuracy of identified optimum is validated using confusion matrix. The variables and formulae used to compute accuracy is as follows,

a) **Rate of optimum path as optimum (True Positive):** The rate of optimum path is considered as optimum path which is True positive rate (I_{tp}).

$$I_{tp} = \frac{\sum V_i}{|Y|} \;\forall\, i \in Y \qquad V_i = \begin{cases} 1, & if\ v_i = o_i \\ 0, & if\ v_i \neq o_i \end{cases}$$

Y = (v o) where v is the value of denoted path (0 or 1) and o is the original status of the path $P_i \in P$. The true positive rate is given in figure 6 for 10, 20, 30, 40 and 50 nodes with fixed node density. The performance of proposed algorithm is better when number of nodes is less.

b) **Rate of Non-optimum path as Non-optimum (False Negative):** The rate of non optimum path is considered as optimum path which is false negative rate (I_{fn})

$$I_{fn} = |Y| - I_{tp}$$

Where Y is the number of iterations; I_{tp} is correctly identified the optimum path as optimum path.

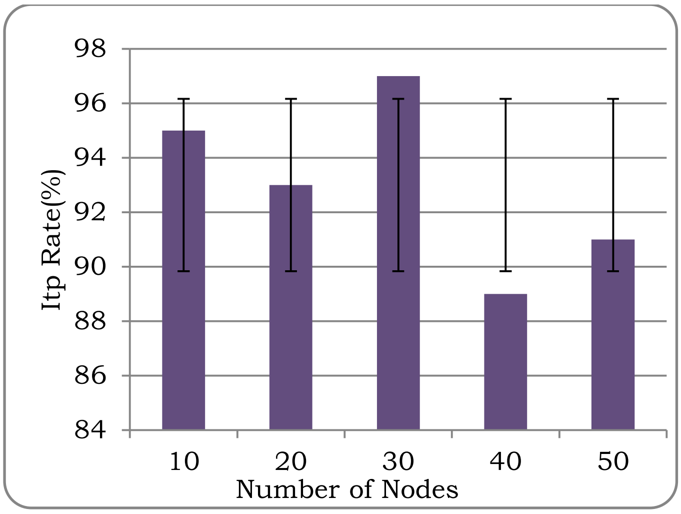

Figure 6. True Positive Rate.

c) **Rate of Non-optimum path as optimum (False Positive):** The rate of non optimum path is considered as non optimum path which is false positive rate (I_{fp}). The false negative rate and available paths are linear functions. The false positive and false negative rates are shown in figure 7.

$$I_{fp} = \frac{\sum U_i}{|X|} \forall i \in X \qquad U_i = \begin{cases} 1, & if\ u_i = o_i \\ 0, & if\ u_i \neq o_i \end{cases}$$

d) **Rate of optimum path As Non-optimum (True Negative:** The rate of optimum path is considered as non optimum path which is true negative rate (I_{tf})

$$I_{tn} = |X| - I_{fp}$$

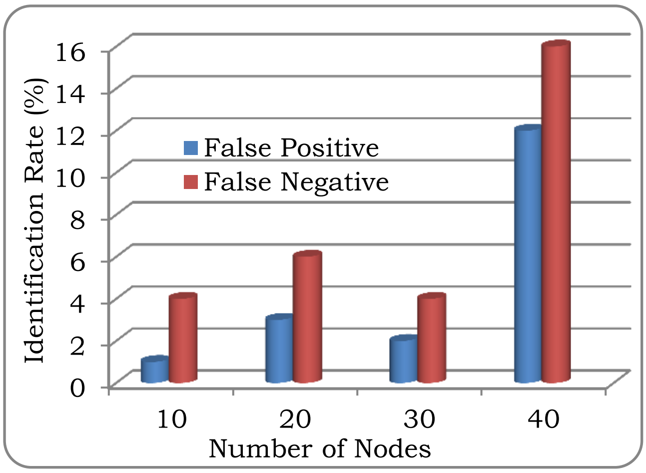

Figure 7. False positive and false negative

QoS metrics

Packet Delivery Ratio (PDR) is the fraction of delivered packets and sent packets.

$$\textbf{PDR}= \frac{Number\ of\ packets\ Received}{Number\ of\ packets\ Sent} * 100$$

The packet delivery Ratio and packet drop rate for TOPQoS and LOADng are compared as shown in the figure 8. The outer ring points indicate number of nodes and inner points indicate the percentage. When the number of nodes is less, LOADng performance is better than TOPQoS. The performance of TOPQoS is much better than LOADng when the number of nodes is high.

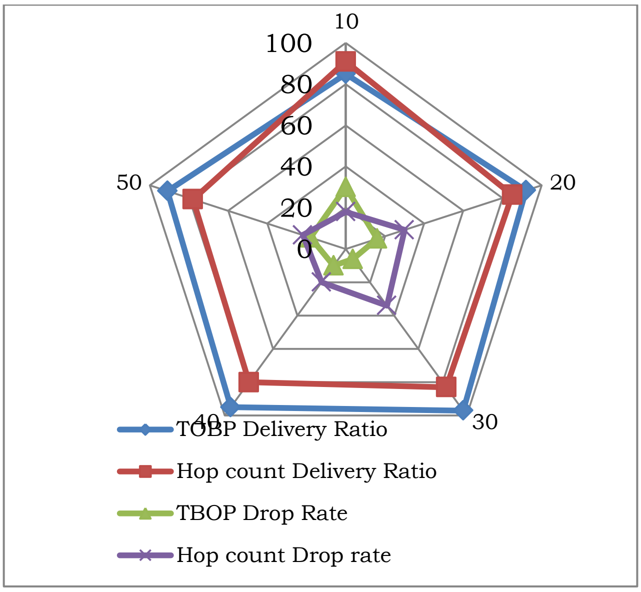

Figure 8. PDR and packet Drop Comparison

Emulation

The smart home case study is emulated using cooja with three different types of hardware boards. The hardware specification used for emulation is tabulated in table 5.

Table 5. Hardware specification

Node Type	Processor	Storage (RAM\Flash)	Physical layer
Mica 2	ATmega128L (8 bit)	4\128 (KB)	CC1000 (38Kbps)
Tmote Sky	TI MSP 430 (32 bit)	10\48 (KB)	CC24200 (250Kbps)
Imote2	IntelPXA271 (32 bit)	32\32 (KB)	CC24200 (250Kbps)

The figure 9 shows total number of paths available in the network and total number of paths between source and destination. It is further divided into paths with and without attacker node.

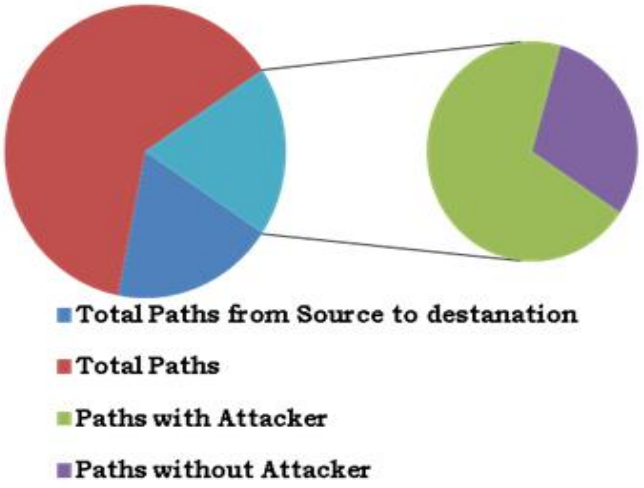

Figure 9. Available paths and attacker ratio

The timeliness and Reliability are emulated for smart home case study. The results for LOADng and TOPQoS are compared in the presence and absence of attacker node. The * symbol indicates the presence of attacker node as shown in figure 10.

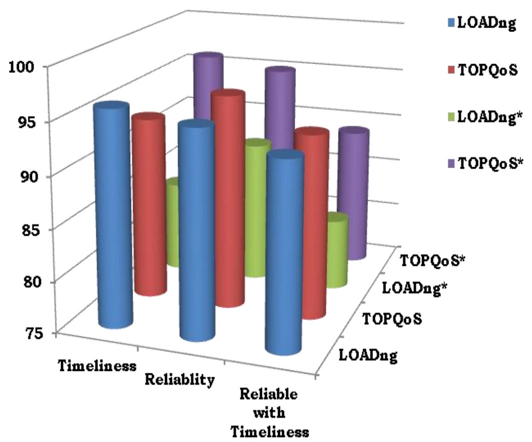

Figure 10. QoS comparison

Timeliness

The timeliness is referred as packet from source that must reach the destination before the end to end threshold time. This threshold value is application dependent. If the destination doesn't receive the data packets within the threshold time the application may fail.

VI. CONCLUSION

Since IoT devices are resource constrained devices, routing is a challengeable task. The QoS in routing differs from data to data. The real time data sacrifice the reliability but not sacrificing delay. Whereas non real time data sacrifice delay and do not compromise the reliability. The existing algorithms achieve the Quality of service by sacrificing some other QoS parameters. The proposed TBOP model identifies optimum path with five parameters. Thus, the obtained path enhances the quality of service in routing. The five order TENSOR model dynamically identifies the path and the parameter is also dynamically changed. The proposed algorithm identifies the optimum path with the average rate of 93% as True positive Rate (ie the optimum path is identified as optimum path). 4% and 6% are the average rate of False positive and False negative respectively. The proposed algorithm is compared with LOADng Protocol with Hop count as path metric. The algorithm proved better performance when the number of nodes increases.

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