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SRHM: SUSTAINABLE ROUTING FOR HETEROGENEOUS ADHOC ENVIRONMENT IN IOT-BASED MOBILE COMMUNICATION

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Abstract: Incorporating Heterogeneous Mobile Adhoc Networks (HMANETs) in upcoming Internet-of-Things (IoT) environment will call for evolving up with a novel inter-domain routing that is capable of sustaining the uncertainties of dynamic topologies in HMANETs. Literature highlights lack of any such routing technique in IoT. Therefore, the proposed manuscript presents a novel Sustainable Routing in HMANETs that is exclusively carved for establishing seamless communication among the mobile nodes. A novel strategy of gateway-to-gateway communication is also presented using a sophisticated mathematical modeling that is proven to minimize the search time for the destination node irrespective of any traffic situation. The outcome shows a good balance between communication performance and computation methodology used for establishing seamless inter-domain routing in HMANETs environment.

Keywords: Heterogeneous nodes, Mobile Adhoc Network, Inter-domain routing, Internet-of-Things

I. INTRODUCTION

MANETs have been frequently visited by various researchers in wireless domain owing to various research problems associated with it. Irrespective of ranges of problems such as energy [1], routing [2], security [3], traffic management [4] and so on, we find that majority of the problems surface from its inherent decentralized nature and dynamic topology. Application of MANETs has been not only restricted in vehicular networks, but there are researches [5][6], which motivates the usage of MANETs in IoT. A closer look into IoT applications shows that it is mainly formed by connectivity with smart devices and sensors mainly [7], which is more or less dependent on fixed infrastructure. However, conventional MANET system cannot be applied to IoT as it normally considers homogeneity in its network and node structure. In order to support IoT based connectivity with MANET, the heterogeneity of the nodes and protocols has to come within the networking features [8]. Owing to presence of multiple communicating devices, heterogeneous routing protocol will need to be incorporated within the networking protocol that also highlights about its dependency on a need of new gateway [9]. Therefore, this paper presents a novel idea where heterogeneous MANET system has been constructed with newly formed inter-domain routing in order to assist in seamless and reliable communication among the mobile nodes. Presented with an aid of mathematical modeling, the proposed framework is found to offer better transmission performance with optimal resource usage. Section 2 discusses about the existing research work towards MANET communication protocols and research on communication in IoT followed by research problem identification in Section 3. Section 4 discusses about proposed methodology followed by elaborated discussion of mathematical modeling as well as algorithm implementation in Section 5. Comparative analysis of accomplished result with existing inter-domain routing is discussed under Section 6 followed by conclusion in Section 7.

II. Related Work

This section briefs regarding the research contribution of inter-domain routing techniques and various forms of communication techniques used in adhoc network as well as IoT. Yuste et al. [11] have presented a mechanism to discover the gateway in MANET considering the energy factor of a link in heterogeneous environment. Studies towards heterogeneous MANET system has also been carried out by Wang et al. [12] considering conventional border gateway protocol. Zhao et al. [13] have presented a clustering technique for establishing communication in heterogeneous MANET in order to minimize the level of interference caused by nodes working on high power. Manjappa and Guddeti [14] have implemented swarm intelligence for developing an optimized routing in MANET. Although, such techniques offer establishing communication among the heterogeneous mobile nodes, but they least assure the scalability in performance. Addressing the problems associated with the scalability has been presented by the Xiang et al. [15] but it lacks considering heterogeneous network. The significant work carried out by Grandhomme et al. [16]has presented an inter-domain routing in MANET considering the tactical applications. Study towards inter-domain routing has also been carried out by Okundaye [17] for similar purpose. There are also certain recent work being carried out emphasizing on the routing demands in IoT by addressing problems associated with security [18], energy [19], multimedia communication [20], knowledge acquisition [21], navigation system [22], load balancing [23], intelligence communication system [24], long-distance communication [25], industrial communication [26], incorporating cognitive-based communication [27], developing self-organizing routing scheme [28], enhancing performance of routing [29] etc. The work carried out by Bellavista et al. [30] have discussed about the possibility of integration of mobile adhoc network and sensor network. Hence, existing research attempts have bi-directional focus on adhoc network and IoT where there are less standard research attempt towards addressing the problems associated with adhoc network in IoT. Existing research work has dominant focus on enhancing routing protocols schemes associated with sensory-based communication in IoT and well as splitted focus on vehicular network. The next section outlines the problems associated with existing research contribution.

III. Problem Description

After reviewing the existing approaches from prior section, following research problems have been surfaced:

- *More dominancy of sensory application*: Although, IoT will predominantly use sensors in order to acquire its primary sensory data, but IoT applications are never restricted to only sensor networks. It is because sensors are just the economical means of capturing the data. At present, there are various cloud-based applications that have lesser dependencies on sensors (viz. navigation system, social network, behavior tracking etc).
- *Challenges in incorporating MANETs*: The biggest challenge in integrating MANETs with IoT is that MANET is completely infrastructure - free while IoT has an explicit infrastructure. Hence, designing a mechanism in order to integrate both will call for major research challenges towards baseline protocols first. The second challenge in incorporating MANET in IoT will be to perform an update of the routing operation.
- *Inapplicability of existing inter-domain routing*: Existing routing techniques pertaining to inter-domain communication make use of border gateway protocol. There are various studies in existing system that has reported problems in usage of such protocols as they are more prone to internet-based architecture where dynamicity of topology is very less. They were never meant for dealing with sophisticated adhoc networks in IoT. Hence, existing inter-domain routing cannot be applied for adhoc communication in IoT.
- *Degraded Communication performance*: Existing approaches of routing techniques mainly emphasize on shortest path and any specific criteria of selection of routes e.g. energy-efficient routes. However, such selection process may not be efficient enough when it comes to dynamic topologies where the communication link cost changes every second with mobility. Hence, although such approaches successfully establishes connection, but they never guarantees that how long such connection can be hold. This often results in packet loss giving rise to degraded communication performance.
- *Ignorance to Resource Utilization*: It is evident that IoT has infrastructure and thereby there are various resources from ground application to cloud application associated with it. Existing routing approaches are found not to emphasize on conserving resources and thereby balance the communication performance at same time. Maximum resource utilization will also result in increase in cost although performance may also increase. Hence, there is lack of any literature where resource utilization is focused on when performing inter-domain routing in IoT-based application.

The above research problems are addressed in proposed system by evolving up with a framework to integrate heterogeneous MANETs with IoT. The next section outlines the research methodology used for overcoming such issues.

IV. PROPOSED METHODOLOGY

The present work is an extension of our prior work towards inter-domain routing [31]. The design of the proposed system considers mainly analytical modeling strategy where the prime goal is to ensure establishing sustainable routes for the mobile nodes under IoT-based traffic environment.

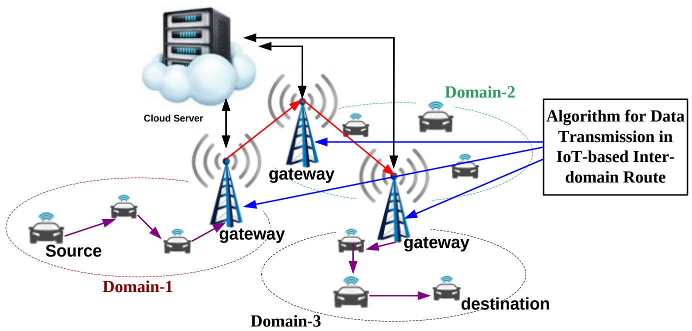

Figure 1 Proposed Implementation Scheme of SRHM

We consider futuristic reconfigurable network where heterogeneous mobile adhoc network is integrated in IoT. Figure.1 highlights the implementation scenario of our proposed system.

In this section, we illustrate the functionalities and features being designed for the proposed inter-domain routing.

- *IoT Environment*: We formed an IoT environment considering various sensors equipped both on mobile nodes (or vehicles) as well as on other hot spot areas (e.g. femto cells). Each mobile node communicates only after registering its identification with the domain that is controlled by a gateway node. The gateway node collects all the transactional data and stores it in cloud server in order to perform an analytical operation. The purpose of integrating the gateway node to the cloud server is to offer ubiquitous computing for query processing generated by any source mobile nodes.

- *Domain*: Domain can be treated as group where a specific routing protocol is being exercised. It will also mean that different domain executes different adhoc routing protocol which combinely formulates a heterogeneous MANET system.

- *Gateways*: Basically, this is a special node with resources that facilities in processing heavier task. A policy for message conversion among different routing protocol is maintained in cloud server which has to be visited each time when the gateway node is required to communicate with other gateway with different domain (or routing protocol). For faster execution of query processing, each gateway node upon successfully forwarding the message sends the updates about its operation in the cloud server that automatically is accessed by the other gateway node. This procedure significantly assists in updating the gateway and minimizes the search time for the destination node. Each gateway mainly executes hybrid protocol present in adhoc network; however it can also process any form of other routing protocol too (either on-demand or table-driven). The software running the algorithm is hosted in cloud server and is executed by the gateway node.

The above mentioned points are the essential modules in the proposed SRHM that uses an explicit mathematical modeling in order to establish sustainable routes in heterogeneous MANET system. The flow of the work is as follows: We consider that each domain consists of certain number of mobile nodes which are required to be registered by the respective gateway node in order to avail the communication services by the gateway node. This process is carried out for all the other mobile for which reason a gateway node retains almost all the dynamic information of a vehicle i.e. velocity, location, request ID, etc. According to this protocol, a query is generated by the source node that is passed upon to the respective gateway node using broadcasting. Upon receiving the query, the gateway node should execute a process to solve the query. For this purpose, the gateway node has to access the cloud server at uniform interval of time in order to get updated itself. This operation will mean that upon receiving the query from source node, the gateway node will have list of alternatives to reach the destination node in different domains using their respective gateway node. The message translation is not a difficult job for a gateway as a message conversion file is maintained within the cloud server which explicitly maintains conversion of one to other routing protocols in adhoc network. Hence, after the message conversion is successfully carried out, each gateway can perform data communication with each other. However, the proposed system does not perform any data communication and instead look forward to further shortlist the routes by eliminating certain gateways that could be less helpful for them. For this purpose, node density factor is highly emphasized. The proposed mechanism assumes that more dense area could offer more probability of obtaining the location of destination node. Hence, only those gateway nodes are considered which have higher node density. However, higher node density could also offer redundant data and may waste lot of valuable resources. This problem is eliminated by further computing the channel and node-to-node correlation between the requested gateway and shortlisted gateway. In this process, the requester gateway node discards all the information about the node (recommended by other gateway) with less correlation and further narrow down the search process. Further, it also uses channel state information to further reconfirm the quality of channel to be established. In shorter, the proposed system offers a non-recursive process of confirming the strength of the inter-domain routes in order to select the best gateway as well as best communication channel. An elaborated discussion of mathematical modeling is discussed in next section.

V. Mathematical Modeling

A simple mathematical model assists in incorporating a novel inter-domain communication principle that enhances IoT architecture. In order to implement this, we consider the case study of smart traffic management system in IoT. A random process of a source mobile node *I* is as follows.

$$\sigma_i = \sum_{k=1}^{K} \sigma_k \tag{1}$$

The above expression shows a standard random process of i^{th} source mobile node under a specific domain communicating with j^{th} destination mobile node. For challenging scenario, we consider the positioning of j^{th} destination mobile node in some other communication domain in order to construct inter-domain routing in IoT. Consider that k ($k \subseteq K$) represents the size of the road segment where the vehicles are moving with a speed range [s_{max} s_{min}]. Therefore, we use probability mass function in order to represent the random process of the mobile nodes as,

$$h_{\sum n \to \phi} = a.(d.\phi)^n.b \tag{2}$$

The study considers that initially the mobile nodes move around with same speed that finally switche between the ranges of [s_{max} s_{min}]. The expression (2) is used for assessing the traffic density considering density *d* of the mobile nodes. The variable *a* and *b* in Expression (2) represents traffic coefficient computed using 1/n! and $e^{-d\phi}$ (where $n>0$) respectively.

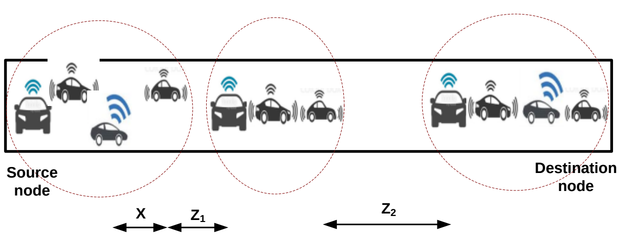

Figure 2 Pictorial presentation of domain formulation by the mobile nodes

The study considers that *X* is the spatial distance between the mobile nodes under same domain and is less than transmission range T_{RX}. We also consider that *Y* is the spatial distance between the preliminary mobile node and final mobile node in same domain. Let Z be the spatial distance between domain *p* and (*p*+1). Therefore, number of mobile nodes formulating domain is mathematically represented as,

$$g(m)=h.(1-h)m, \; m>0 \tag{3}$$

In the above expression, $g(m)$ represents the probability mass function of *M* mobile nodes (that forms a communicating domain in IoT), where the variable *h* is equivalent to $e\text{-}\sigma^{i.TRX}$. This is an essential formulation as it is deployed for establishing inter-domain routing between two nodes in different domain in IoT. The proposed study uses the probability theory in order to compute the possibility of inter-domain route from i^{th} node to j^{th} node as follows.

$$\mu_{ij} = \sum_{n}^{N} \sum_{r_1}^{r_2} \beta.g(n) \tag{4}$$

In the above mathematical expression, μ_{ij} is represented as probability factor of inter-domain route that exists between two nodes via gateway nodes. The variable [r_1 r_2] represents range of possible minimum and maximum hops established between the mobile nodes in only communicating domains. The variable β represents product of probability of a mobile node with good number of adjacent nodes and probability mass function of cumulative hops in inter-domain routing in IoT.

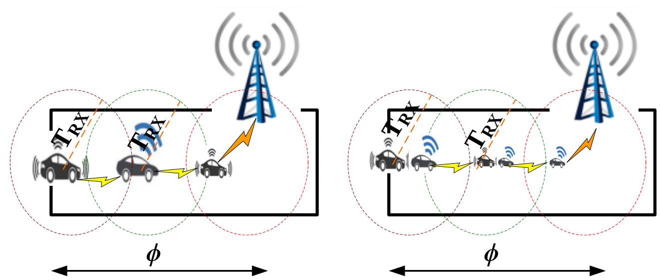

Figure 3 Pictorial Representation of hops establishment

Therefore, it can be seen that a data packet is acquired by the j^{th} node in r_1 hops that can be further computed as ϕ/T_{RX}. Therefore, the other limit r_2 assist us to infer its dependencies for the data packet for reaching j^{th} node. Basically, this mechanism is used for assessing the occupancy level of the selected inter-domain route by the i^{th} source node. Mathematically, the level of occupancy of such routes is computed by monitoring the transmission probability of that route as follow,

$$O_r=1-P_{tx} \tag{5}$$

The system can easily find the probability of transmission P_{tx} by computing $(1-P_{tx})^{\eta}$, where η represents product of node density and range of carrier sense. It will also mean that the variable η will represent the mobile nodes that are explored to confirmly participate in data forwarding process as they come within better probability of range in carrier sensing. This process leads to generation of a positive scenario of visualizing two different channel conditions on the basis of their probability states.

The formulation of the algorithm for data transmission in IoT-based Inter-Domain Routing, where the algorithm takes the input of *s* (speed of nodes), *l* (length of road-segment), *p* (domain), *M* (number of mobile node in one domain), *f* (message fields), *λ* (correlation between two nodes) that after processing yields the outcome of the *msg* (data). The steps involved in the algorithm are as follows:

- *Initialization*: The initialization process is carried out on only few parameters e.g. number of mobile nodes, speed range, domain range etc. We consider that there are M numbers of mobile nodes under one specific domain *p* (Line-1).

- *Network Modeling*: Owing to dynamic nature of the mobility of mobile nodes, the complete network modeling follows random and probability distribution. Mathematical expression (1) is used for formulating the arrival process of mobile nodes (Line-2) followed by random distribution of process σ in all domain *p*. It will mean that a random distribution is allowed to process among all the *M* nodes in different domain *p* at same time *t*(Line-3). This is carried out to formulate the dynamic and uncertain behavior of network in IoT-based traffic model.

- *Communication Modeling*: The process of initiating communication starts from the node distribution within each domain for all the nodes N using mathematical expression (3) as exhibited in Line-6. A source node n_i forwards a request message to its respective gateway node gnode (Line-8) by exchanging different forms of field information e.g. address of nodes, ID, hop, sequence, etc. It can execute both one-demand protocols as well as table-driven protocols further in this step (Line-9).

- *Establishing Inter-Domain Routing*: Once the request has been generated by n_i to g_{node} than gnode computes the probability of the inter-domain routing using mathematical expression (4). However, this computation (Line-10) is carried out by only gnode that has received the request. The other g_{node} that has prior processed such request indexes metadata of such request in its memory in order to assist other gnode to find the destination node information. Based on highest probability among the neighbor g_{node}, the selection of routes among the g_{node} is established. The next step is to compute the channel correlation (Line-12) that offers comprehensive detailing about the density-based information in upcoming domain from their respective gateway. The idea is to perform selection of gateway that has better number of mobile node with higher probability of data transmission. Hence, this is facilitated by computing node-to-node correlation. The highly correlated nodes in different domain are selected to be a part of routing process while less correlated nodes are discarded in the process. However, if the channel correlation-based information is not much well defined, we use threshold Th (Line-13). In case of mobile nodes with higher correlation in explored domain, the nodes are selected in routing process (Line-14) or else they are checked for their Channel State Information (CSI) data (Line-16). It will mean that at any point of time, the proposed system offered guaranteed condition to positively transmit the data packet to the destination node in IoT-based traffic system (Line-19).

Algorithm for Data Transmission in IoT-based Inter-domain Route
Input:*s*, *l*, *p*, *M*, *f*, λ
Output:*msg*
Start
1. inits[$s_{min} s_{max}$], *l*, *p*[$p_{min} p_{max}$], p_{min}<0
2. Model the arrival process of mobile nodes using Eq.(1)
3. Distribute σ_i randomly to all *p*.
4. reg(n_1, n_2, ……n_M)→g_{node}, M<N
5. **For** i=1:N
6. $g(m)=h.(1-h)m$, $m>0$
7. **End**
8. (n_i)p_x→msg(*f*)[g_{node}]
9. **For** j=1:g_{node}
10. Compute probability of inter-domain routes

$$\mu_{ij} = \sum_{n}^{N} \sum_{r_1}^{r_2} \beta . g(n)$$

11. Compute $\tau=\phi^d/\phi^D$
12. Get channel correlation=λ^τ
13. **If** λ^τ>Th
14. Shortlist routes with $n(\lambda^\tau>\text{Th})$
15. **Else**
16. Check for CSI availability
17. **End**
18. **End**
19. Forward *msg* to (n_j)p_y

End

The algorithms exhibited above highlight that proposed system offers a combined solution for selection of a gateway node on the basis of its connection with its subset mobile nodes with more information about the destination node using random modeling. This mechanism not only makes the exploration of the routes faster but also minimizes any form of overheads. The next section outlines the result obtained.

VI. Results Discussion

This section outlines the outcome obtained from the proposed system. The complete implementation of the proposed study has been carried out in ns2 considering 1000 mobile nodes being dispersed in 1300x1400m^2 simulation area. The size of the control message is considered to be 32 bit in standard with 0.3 seconds of time required for channel sensing. The communication is carried out considering 2000 bytes of data packet with each mobile node assumed to have Omni-directional antenna. The movement of the nodes are executed using random mobility with the range of velocity of mobile nodes as [0 60]. For an effective benchmarking, the study outcome of the proposed system is compared with the work carried out by Kaddoura [32] and Chau [33]. These existing studies are highly referred research methodology in inter-domain routing and introduce a mechanism for addressing the problems with communication via gateways in mobile adhoc network. The performance parameters considered are data transmission, response time, and amount of resource consumption in order to carry out comparative performance analysis.

i) Analysis of Data Transmission Rate:

The rate of data transmission is computed by the amount of data being transmitted over a unit interval of time via various gateway nodes. This analysis offers clear visualization of speed of data forwarding process irrespective of increasing traffic condition in increased iterative rounds.

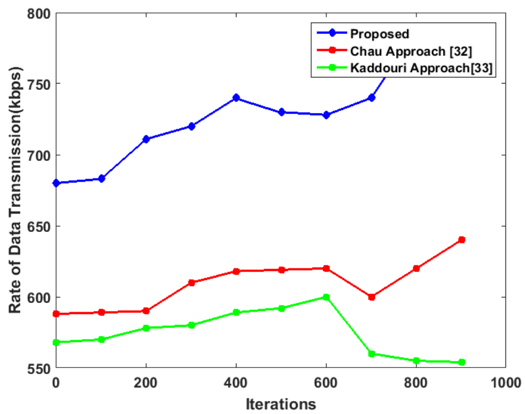

Figure 4 Comparative Analysis of Data Transmission (x-axis: iteration)

Figure 4 highlights that proposed system offers significantly higher rate of data transmission as compared to existing system. The prime reason behind this is periodic exchange of synchronized message among the gateway nodes that keeps a constant updates about the addresses of newly joined nodes or leaving old nodes. This process minimizes the exploration process leading to speeded up the process of data transmission. Moreover, availability of many alternative nodes with better interoperability offers better scalability outcomes for proposed system which is ideal for heterogeneous mobile adhoc network in IoT applications.

ii) Analysis of Response Time

Response time relates to the complete system and is computed by measuring end-to-end delay and algorithm processing time. Analysis of response time offers strategic visualization towards the sustainable possibility of traffic management under dynamic topology and uncertainty environment in adhoc communication.

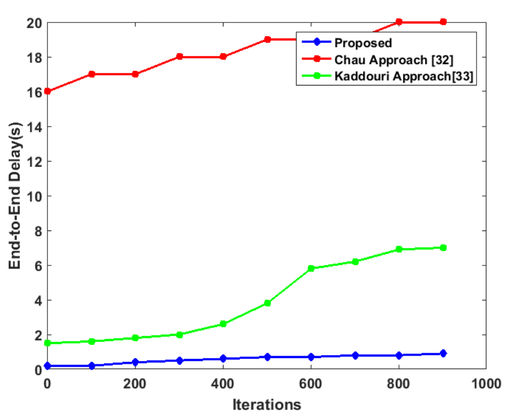

Figure 5: Comparative Analysis of End-to-End Delay

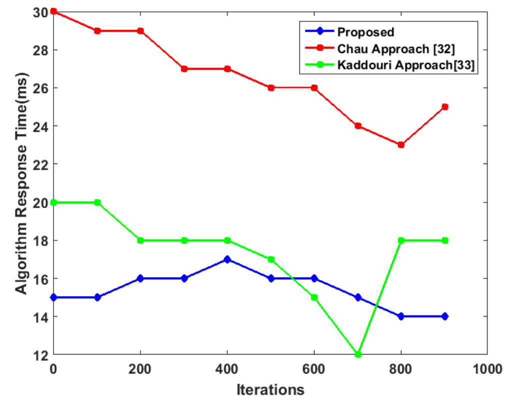

Figure 6 Comparative Analysis of Algorithm Processing Time

Figure 5 and Figure 6 show that proposed system offers highly reduced delay performance and consumes lesser time as compared to existing system. The prime reason behind this is the proposed algorithm offers to use a hybrid protocol (both on-demand and table-driven routing protocols) that allows faster communication when dealing with heterogeneous routing schemes. At the same time, a gateway node maintains a repository of message conversion policy that is periodically updated to all the other gateways resulting in faster query (or message) processing time. Hence, irrespective of increasing traffic load in iterations, response time is almost faster compared to existing system.

iii) Analysis of Resource Consumption

The resource consumption will relate to the amount of the resource being utilized to complete one round of data dissemination process from source to destination node. We consider resource as i) amount of energy being utilized, ii) amount of channel capacity being used, and iii) amount of memory being utilized in order to successfully forward the data packet in inter-domain communication of IoT. We performed modeling of resource as a constant which keeps on minimizing uniformly on the basis of transmission taking place applying probability theory. A resource variable has been formulated that is initialized to 0.5 which is being monitored for its usage statistics uniformly for all the considering routing process.

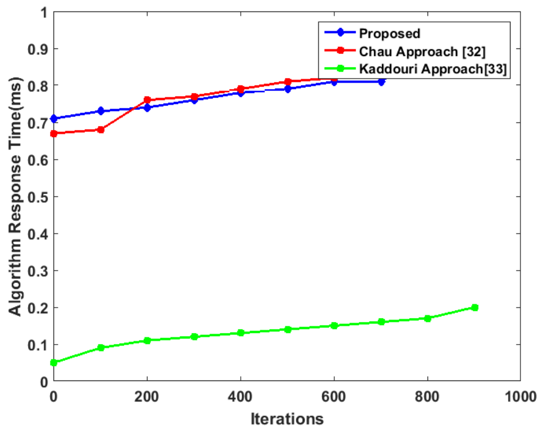

Figure 7 Comparative Analysis of Resource Consumption

The outcome in Figure.7 shows that proposed system uses comparatively less amount of resource compared to existing inter-domain routing approaches. A closer look into the implementation of the proposed system will show that a gateway in enriched with information whenever a request is forwarded or the data is successfully delivered. It is mainly because of seamless synching among all the gateways after uniform interval of time. Hence, global search time for the gateway to find the address of destination node is significantly minimized by the synching process. Moreover prior to synching process of gateway, it computes the probability of mobile node with maximum adjacent nodes further assist in converging the selection process. Therefore, in spite of executing the search mechanism (forwarding the query messages) to all the gateway, the proposed system only considers the shortlisted gateway which directly reduces the message exchanging mechanism (between end gateway and destination node) to confirm the presence of destination node at the other end. Overall, it save approximately half proportion of the resources in this search process which not only saves time but also enhances the network performance that is required in mobile devices operating in IoT environment. Therefore, on the basis of this outcome, we can state that proposed system offers better suitability to deal with uncertain and unpredictable communication demands in IoT application when hosting mobile adhoc networks with inter-domain routing.

VII. Conclusion

There are various challenges associated with incorporating HMANETs in IoT e.g. i) challenge for designing a novel gateway system that can perform message translation faster and efficient ii) challenge for dealing with dynamic topology iii) challenge for selection of predictably sustaining routes, and iv) cost efficiency in design approach. The proposed system deals with all the above mentioned challenges in following manner. i) It formulates a novel query processing mechanism where the cloud server has been incorporated in order to establish a better form of synchronization among the gateway nodes. This assists in faster query processing among the gateway nodes when it receives the route request from any respective nodes. ii) the problems of dynamic topologies has been dealt with by upgrading any form of transactional operation among the gateway nodes with a gap of uniform interval of time. This process assists in uniform sharing of any form of topological information among the gateway nodes with each other resulting in good retention of transactional information. iii) Unpredictability of the routing system has been mitigated by presenting a novel routing protocol that is exclusively maintained for IoT application. iv) the proposed system doe not involve inclusion of any form of additional equipment or hardware. The study outcome significantly shows better data transmission performance with optimal resource utilization that proves its better applicability in upcoming IoT application.

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