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Conceptualization of a Novel QoS-Efficient Enhanced Routing Schema for Wireless Mesh Networks

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Abstract*: Since many years the area of wireless networks provided various solutions to promote a better quality of communication aspects in our day-to-day lives. Wireless mesh networks (WMNs) being a subset, emerging as a promising technology-oriented network as it comprises of a set of key features such as robustness, simplicity in operating conditions, fault-tolerant capability and faster process of deployment. The area has a wide range of commercially deployable applications where the communication gets carried out in multi-hop fashion between nodes. Here, nodes act as both the router and the host. Despite having potential characteristics features WMNs routing and Quality-of-Services (QoS), performance improvement is a key challenge derived in many studies. The formulated study thereby addresses this problem and come up with a novel routing solution to attain better QoS aspects such as throughput performance, delay performance in the context of WMN. The design of the formulated approach applies two prime functional schema i) approaches to handle the QoS problem, and along with this ii) the analytical design and modeling of the formulated routing approach aims to mitigate the hidden terminal problems with extensive quantitative analysis. The mathematical modeling approaches are further computationally executed, and assessment of aggregated throughput, energy, and QoS ratings are retained. Finally, the experimental outcome demonstrated that the presented approach attains better QoS and energy performance improvement (~60% and ~70% respectively) as compared to existing baseline models SOAR and ROMER.

***Keywords:* Wireless Mesh Networks (WMN), Quality-of-Services (QoS), Routing, Energy Optimization**

I. INTRODUCTION

The research evolution trend curve since many years shows that continuous research efforts have been kept towards strengthening the wireless networking features in both communication and routing scenario. The extensive research effort also shows that there exist various areas opened up from the core backbone of wireless network architectural paradigm such as LAN(WLAN)/Wi-Fi, Wi-Max , 4G cellular networks , WSN , VANET , MANET etc [1][2].

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Whereas each of this type of networks contributed various potential applications to enhance the quality of human lives and still under supervision for opportunistic and futuristic IP enabled smart communication systems in the context of cyber-physical systems [3][4]. The advancement of the foundation of wireless networking also evolved up with a new type of devious and promising wireless technology in this IP-world often called as WMN. Considering the matter of fact it can be stated that the , the collaborative paradigm of various types of wireless sub-networks such as Wi-Fi, WLAN , WSN , VANET etc. resulted in WMN broadband and mobile computing[5]-[10]. The conceptual idea behind establishing the communication in WMN clearly states that data should be routed from each radio-node of a specific sub-net to another node of another sub-net by ensuring very minimal latency and optimized QoS performance aspects such as throughput and packet-delivery ratio aspects [11].

There are various studies which have claimed that the successful adequate operating conditions in WMN from both energy and routing perspective could provide several improvised advantages to the conceptualized Internet of Things (IoT) objects[12][13]. Considering the fact that makes WMN more opportunistic requires satisfactory improvement in both energy and routing performance (i.e. in the context of QoS) along with fault-tolerance and robustness. However, the area where both energy and QoS-efficient routing can be optimized are less likely explored in the existing system. Thereby WMN is still cloaked with various pitfalls which confine its futuristic advancement and scope of adaptability and 5th generation networking architecture [14] [15] [16].

The study addresses both routing and QoS problem in WMN and attempted to improve the QoS rating and minimizes the signaling overhead by means of providing a collision free MAC in static WMN. It also addresses multi-path routing problem, congestion and load balancing aspects by deriving an energy-aware QoS efficient routing strategy. The routing model is represented with an optimized algorithm which captures the traffic behavioral attributes to formulated better route in the network-layer. The optimized multi-path routing protocol also designed considering the energy constraints. The analysis of the numerical simulation is performed with respect to key performance parameters which justifies both energy , routing and QoS aspects such as i) Energy consumption per bit , ii)average delay (s) and iii) Throughput performance.

And the analysis also computed Beacon arrival span for the performance analysis purpose. The validation of the model is carried out by comparing the outcome with significant relevant WMN routing approaches such as SOAR and ROMER. In every instances of simulation scenario the formulated system (PRoP) accomplishes comparatively superior outcome which ensures its adaptability into various time-critical applications of Internet of Medical Things (IoM).

The entire research study is organized with respect to different sections such as section 2 discusses about the conventional trend of literatures worked in the similar direction. Section 3 outlines the overall research problem context. Section 4 further illustrates the design methodology of the formulated system (PRoP). Finally section 5 discusses about the result obtained and section 6 present the conclusion of the study respectively.

II. LITERATURE SURVEY

This section highlights most recent relevant studies which have also focused on the QoS efficient routing problems in the context of WMN. The study of **(K. Sundaramoorthy and S. S. Rao Madhane, 2014)** focused on both security and QoS amplification problem in WMN. The study introduced a secure routing scheme which also provides QoS aware routing. The simulation outcome shows that the scheme performs well towards maximizing the throughput performance [17].

(R. Murugeswari and S. Radhakrishnan, 2014) also focused on energy-aware data delivery performance in WMN where the conceptualization of the approach is application oriented. The target application area is emergency and disaster recovery in the context of WMN. The following table highlights few other approaches and their significant contribution towards similar problem [18].

Table 1 Few related studies on WMN

Cite	Problem Area of WMN	Approach
(R. Sousa , 2010) [19]	Effective video content streaming	GOP based encoding
(L. Ndlovu, M. Lall and O. P. Kogeda,2016) [20]	QoS problem	Investigational study
A. M. Mashraqi and T. Erlebach[21]	QoS problem (Delay –aware)	Delay-aware routing
A. F. Aji, P. Hatta and E. S. Wihidiyat,[22]	Throughput optimization	Distributed scheduling approach
(Y. Li, X. Zhang and X. You,2010)[23]	QoS problem	QoS assurance for IEEE 802.16

There are few other studies like **(Y. Gao, H. Zhang, D. Yang and X. Lu, 2014)[24]** , **(I. Armuelles-Voinov, J. Chung-Miranda and A. Chung-Cedeño , 2014) [25]** , **C. Roy and J. Grégoire** , **[26]** also focused in the similar problem of QoS efficient routing in the context of WMN networking operations.

III. RESEARCH PROBLEM

After analyzing several existing studies it is realized that formulating a QoS efficient routing protocol for WMN is a crucial task due to several factors such as i) Hidden node problem , ii) exposed node problem etc. Considering the fact of research trend curve also exhibits that there are very lesser studies which have explored both energy and QoS efficient routing in WMN. However, complex topological representation also makes WMN routing scenario quite challenging and very lesser routing protocols can adapt to that specific type of situation due to higher complexity, poor scalability and slower convergence performance. Thereby the problem statement of the study can be derived as: "To **design a QoS efficient routing protocol with energy efficient operating condition is computationally a challenging task in the case of complex network like WMN**".

IV. CORE DESIGN CONCEPTUAL BACK-BONE

The design goal of the formulated system in this context aims to improve the Quality-of-service performance in wireless mesh network (WMN) operations such as efficient multi-hop route formulation and data transmission, well-organized resource scheduling, traffic modeling and load balancing etc. The architecture is defined on the basis of underlying service oriented modeling where a set of functional block are introduced in the form of analytical design. The core-backbone of the formulated system consisting of several numerical functional blocks as shown in the following figure 1.

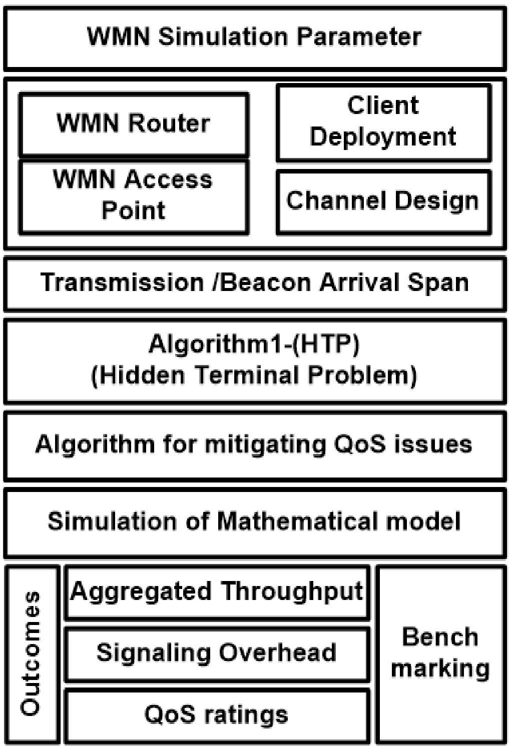

Fig.1 Design Methodical functional blocks

The prime agenda of this approach is to formulate an optimized service oriented algorithm which can ensure better traffic management in the form of key-technological enabler of multi-hop routing in a WMN.

The traffic-management strategy also formulates better resource scheduling by handling the congestion under variable traffic-load to satisfy the Quality-of-Service (QoS) requirements. Here the QoS requirements are justified with two different prime attributes such as throughput and average packet delay. The hypothetical design of the system model also considers that network should exhibit higher throughput fairness under variable traffic load and also it should not affect much the energy performance of WMN networking operation. The optimized routing design also balances the energy performance without affecting much the QoS aspects. The following are subsequent functional blocks used to design the entire routing framework for WMN.

a) Network Modeling Functional Block: The initial process of analytical formulation involves network modeling to realize the architecture of WMN client deployment scenario. For the purpose of WMN client node localization, the analytical foundation initially considers number of clients (nC) and also initializes the specified area of client deployment (cA). The network modeling also further considers inclusion of an WMN access point terminal (A_{Point}) anywhere in the cA. The analytical formulation shows that $\forall C \cup A_{point} \in Z^{+}$. The computational process is modeled in a way where random distribution of clients (C) is targeted within cA. The generation of x_c and y_c is realized to perform localization of each WMN clients with a random function $\phi_1(nC)$.

The visualization of the WMN nC , cA can be realized by simulating the mathematical modeling in a numerical computing tool and The network model can be shown as below:

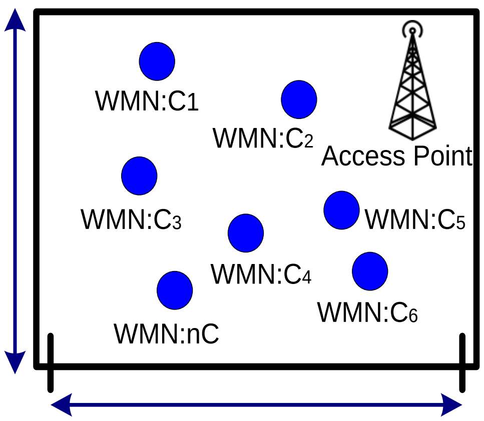

Fig.2 Visualization of the formulated WMN

Figure 2 shows the network deployment scenario of WMN in the formulated context.

b) Algorithm (HTP) Functional Block: Further shows the subsequent functional block to activate the algorithm1 (HTP) that is to mitigate the hidden node problem (HTP). For this purpose the analytical formulation initializes a set of operational parameters as listed below:

Table 1 Quantitative Network Parameters for Algorithm-1(HTP)

Simulation Attributes	
Beacon Interval Span (bIs)	1 to 10
Radius(tr)	27
Active Transmission Period(aTp)	0.15
SynMsg(Sm)	0.03
PermMsg(Pm)	0.12
PrioDatMsg(Pd)	0.68
CnfMsg(Cm)	0.17

This functional block in the initial phase of computation compute the distance from each client to another client in the process of establishing the connectivity with respect to the increasing Transmission Range (tr). The computed value of distance (d) is then stored into a matrix called as $\theta_{Xc,Yc}[]$. The process also computes tr and execute links/connectivity between nC considering a condition that is if $d \leq tr$. The computed links are then stored into a vector cal l[]. Further each client node the the l[] get updated with the following eq.

$$Up\_l[] \leftarrow \sum l[tr,i] \text{ where } \begin{cases} 2 \leq tr \leq 40 \\ 1 \leq i \leq nC \end{cases} \quad \text{eq. 1}$$

Further the computational programmable module $\phi_2(l[])$ executes the optimized algorithm to overcome the HTP. The computational process involved into assessing the algorithm-1 for HTP is discussed as follows:

Algorithm: Routing Algorithm for Resisting Hidden Terminal Problem in WMN
Start
1. Initialize: bIs , tr , aTp , Sm , Pm , Pd, Cm
2. Activate($\phi_1(nC)$)
3. Activate($\phi_2(l[])$)
4. for each(nC)
5. Define link matrix l[] using eq. 1
6. check l[] s.t if $d \leq tr$ then FlagValue ==1
7. Else 0 //not connected
8. end
9. make diagonal value = 0
10. end
11. Activate optimized routing using $\phi_3(l[], nC)$ // **optimized Djkstra's algorithm**
12. Compute [C_{matrix} , R_{matrix}] $\leftarrow \phi_3(l[], nC)$ //**cost evaluation**
13. Execution till end.
End

Algorithm1 is intended to restrict the HTP during the routing scenario thereby it is analytically modeled and realized in a numerical computing environment. The background of HTP shows that it increases network overhead by creating simultaneous traffic overload in the MAC layer which in longer run affect the throughput and network latency and also have a negative impact on the energy performance. The algorithm addresses this issue by introducing an enhanced Djkstra's algorithm. Here if nodes are connected then the flag value become 1 else become 0. Finally Djkstra's algorithm attain the cost matrix(C_{matrix}) and optimized route (R_{matrix})where reliable data transmission with optimized delay and QoS performance can take place. The further process will apply a cost effective mode of classifying the WMN, nC into separate groups. The process activates an empty matrix of Gr[] and further computes the 1-hop neighbour of C. If the condition applied to compute the 1-hop neighbour doesn't get satisfied with respect to numerical threshold modeling then further the module computes 2-hop neighbours of C.

The entire computed route information is then stored into Gr[Info]. This computational module of the reusable framework is denoted with $\phi_4(nGr)$ where the input pipeline defines the number of groups nGr. The computational procedure further initiate a group based schedule-timings for each client where each group of client can communicate with each-other through effective time-synchronization. The process in this phase also restore the group(id)s which are active and time-synchronized for a specified interval of time. Within schedule-timings, one *C(m)* will forward sync msg to its adjacent neighbour *C(k)* and within that scheduled interval communication will take place for all the timing slots. Further the computational process define a data priority level (dPl) to mitigate the data scheduling and forwarding of packets (msg) under variable traffic-load. Finally a functional block $\phi_5(dPl)$ is applied to satisfy the QoS requirements of WMN. The computational model also got validated by comparing its outcome with the conventional approaches of SOATR and ROMER. The next consecutive section will illustrate the outcome obtained after simulating the functional modules of the proposed routing approach in a numerical computing environment. The experimental result analysis is performed considering three different key performance parameters. The elaboration of the experimental outcome obtained further illustrated with a proper quantitative analysis of data. The correctness of the simulation outcome is justified with respect to conventional baseline modelings.

V. EXPERIMENTAL ANALYSIS

The numerical modeling of the formulated approach is functionally realized in MATLAB which is supported with minimum 4GB internal memory and Intel Core i5 processing unit. The following are the quantitative analysis which justifies the energy and QoS performance in WMN routing scenario. The following figure 2 shows the comparative performance assessment of energy performance where inferencing clearly shows that in the case of formulated system energy aware transmission impose very lesser energy per bit and on the other hand it is quite higher in the case of ROMER where SOAR poses more or less similar outcome.

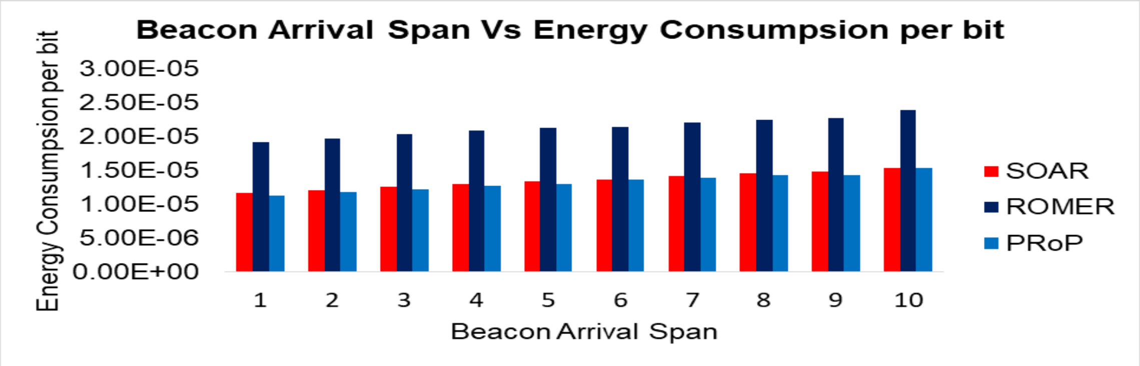

Fig.2 Quantified Outcome of Energy consumpsuion per bit

Figure 2 thereby justifies that the formulated system attain better energy performance as compared to the existing baseline modelings. The study also evaluated QoS performance of the formulated system as shown in the following figure 3 (Average Delay Analysis) and figure 4 (Average Throughput Analysis).

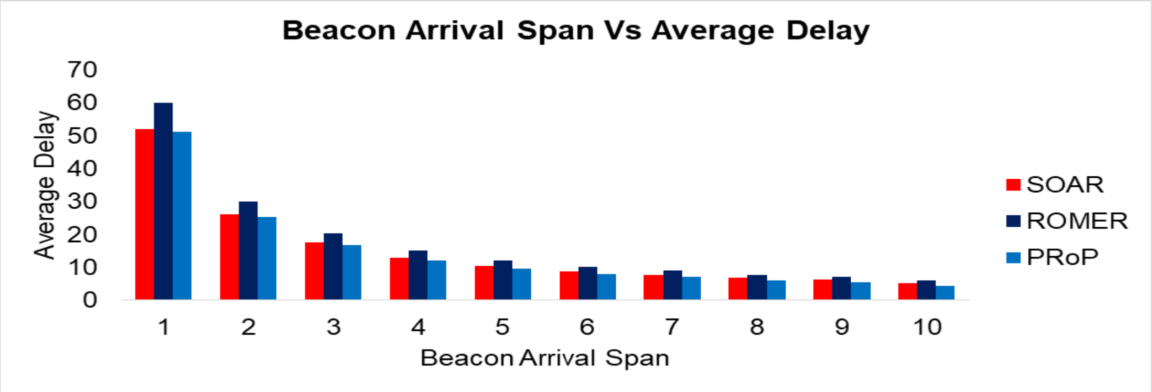

Fig.3 Quantified Outcome of average delay

The quantified analysis shows that the formulated system accmplishes better outcome in delay minimization with increased value of Baecon Arrival Span which is quite higher in the cases of SOAR and ROMER. As the study also focuses on Thorughput maximization thereby analysis of thorughput assesment is crucial from the numerical evaluation view-point. The extenisive outcome of thorughput is highlighted in the below figure 4. The analysis is carried out with respect to baecon arrival span and aggregated thourhgput performance.

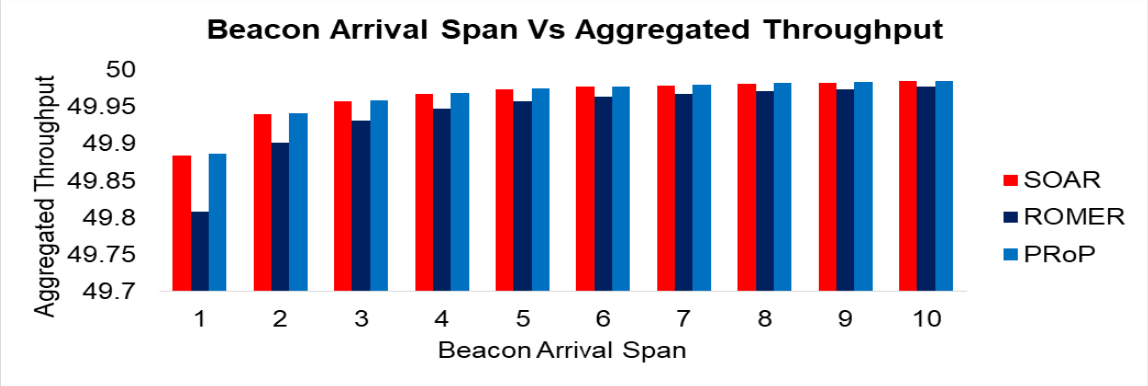

Figure 4 Quantified Outcome of remaining energy

The analysis of throughput performance also shows that the formulated system is quite robust and also consistent to deliver better throughput performance in variable traffic condition and route establishment scenario. However overall it can be concluded that the formulated approach is QoS efficient in route optimization while maintaining better energy performance in the context of WSN.

VI. CONCLUSION

The area of WMN received enormous research effort towards improving the routing and communication performance. Considering the matter of fact that WMN deals with potential time-critical application requirements in practice such as it attempts to fulfil the dynamic QoS demand in various aspects such as health-care, defense, body area networks (BAN) etc. Despite of having potential scope of research the conventional research gap explored shows that majority of the studies are only limited to theory and do not define broader scope of WMN into futuristic industrial Internet of Things (IoT) communications. It is also found that energy and QoS efficient commercialized applications are yet to be implemented with higher throughput characteristic. The presented research study thereby introduces a novel QoS-efficient routing schema which aims to minimize the hidden node problem and also employ efficient time-synchronization scheduling to maximize the QoS performance in WMN. The methodology adopted analytical modeling and numerical computation to realize the algorithm performance in terms of delay-aware routing and energy efficiency. The methodology is formulated with mathematical notion and the design requirement of the system is also extensively illustrated with client deployment and channel design. The study considers analysis of outcome with respect to three prime simulation attributes such as energy , aggregated throughput , and delay performance scenario. The performance analysis shows that the system performance got improved ~78% in the context of throughput optimization. The comparative performance assessment also shows that the formulated approach provides promising outcome in terms of delay and energy as well , in contrast with existing baselines such as ROMER and SOAR.

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