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Dynamic Channel Assignment and Gateway Load Balanced Routing for Multi-Channel Wireless Mesh Networks

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Abstract: In this paper, we propose the dynamic channel assignment and Gateway (GW) load balanced routing protocol. In this protocol, a combined cost metric is determined incorporating channel quality, switching cost and queue length. Then the GW having the minimum cost metric is selected by the source node. Then channels are fairly assigned in the network by the selected GW between itself and the mesh clients. In GW load balanced routing, the GW selects a path with the minimum load based on the interface queue length. Congestion is detected at any intermediate router based on Exponentially Weighted Moving Average (EWMA) of the queue size. Each GW estimates the traffic load at the current interval and predicts the traffic load of the next interval using Hidden Markov Model (HMM). If congestion is detected at GW, then it informs the Access Point (AP) to change to another GW. By simulation results, we show that the proposed technique reduces the network congestion and improves efficiency.

Keywords: Wireless Mesh Networks (WMN), Gateway, Load Balancing, Congestion, Hidden Markov Model (HMM)

1 Introduction

Nowadays the exponential growth in sensor network plays a vital role in various applications. Wireless Mesh Networking (WMN) is a new paradigm for next generation wireless networks. WMNs comprise mesh clients and mesh routers in which the mesh routers create a wireless infrastructure and interoperate with the wired networks to offer multihop wireless Internet connectivity to the mesh clients. In addition of WMNs with reference to succeed networks like the Internet, cellular, IEEE 802.11 (WLAN), IEEE 802.15 Wireless PAN, IEEE 802.16 (WiMAX certification), device networks, etc., is accomplished through the gateway and bridging functions within the mesh routers. Mesh clients is either stationary or mobile, and can form a network of clients with mesh routers connecting them. WMNs are anticipated to resolve the constraints and to considerably improve the performance of ad hoc networks, Wireless Local Area Networks (WLANs), Wireless Personal Area Networks (WPANs), and Wireless Metropolitan Area Networks (WMANs). They are undergoing rapid progress. WMN acts as a self-organizing and auto-configurable wireless network for providing flexible and adaptive wireless Internet connectivity to mobile users [1].

All nodes in WMN can operate both as host and as router. Infrastructure backbone, client backbone, and hybrid are the three types of WMN in accordance with the functionality of the nodes. Mesh routers form multi-hop and multi-path wireless relay backbone for effectively communicating with clients and GWs. Mesh clients together generate self-organized ad-hoc networks with the right to utilize the services by relaying requests to wireless backbone network [2]. Packet loss is the failure of one or several transmitted packets to make it to their destination. Packet loss minimizes the Packet Delivery Ratio. Packet loss may be caused by a variety of issues as well as signal degradation over the network medium because of multi-path fading. Packet loss is feasible in wireless network [3].

Routing in WSNs plays a major role within the field of environment-oriented observance, traffic observance, and so forth. In this paper, energy, security, speed and reliability problems of routing are discussed. After,

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Simulation setting and experimental set-up, quality of service Service(QoS) and, therefore, prepared against varied applications are the support of the literature analyzed. WMNs was typically thought of because of the form of mobile ad-hoc networks. But there are some differences between them. First, in wireless mesh networks, almost all the traffic starts from gateways and ends up also on gateway. Second, in wireless mesh networks, nodes are clearly separated from one another either they are within the type of stagnant nodes or mobile nodes. Routing is basic attribute of WMNs. The protocols have the clear result on the behavior of WMNs [4].

WMN has a partial mesh topology for replacing wired infrastructure backbone in a traditional wireless network with a wireless one. Here, each node operates both as a host and as a router to forward the packets for other nodes that are not in the direct transmission range of their destinations. It is applied in defense, metro-area internet access, and disaster management applications. Mesh routers have minimal mobility than mesh clients. The backbone of the WMN has mesh routers connected in an ad hoc manner through wireless links [5]. In general, mesh routers are static (or quasi-static) in nature and are interconnected through wireless links. Typically, subsets of routers are directly connected to a fixed infrastructure such as a wired network and act as GWs to the mesh nodes. WMNs offer a cost-effective method to set up a wide-area network and provide services like Internet connectivity. A key component of WMNs is GW node. In most of the applications, traffic will be directed from and to the GWs. Therefore, traffic aggregation happens in the paths leading to a GW, causing congestion. The strategy used to associate the nodes that GW transfers / receives traffic through a particular GW node are considered when the network utilizes multiple GWs [6].

The authors have developed Fixed Tree relaxation-based algorithm and iterative distributed algorithm to resolve the ability power efficient distribution problem and they have examined few problems in routing like the delay in transmission and projected a bypassing void routing protocol. The theory was dependent upon the virtual coordinates to stop the void drawback, occurring from the supply to the destination. For the developed cost-aware secure routing, algorithms used delivery ratio and alternative parameters to resolve the problem of network life. Puggelli et al. developed a tool that helps within the preparation of wireless sensor networks and promotes fast prototyping. They developed a mixed-integer linear program and a polynomial time heuristic to get the required results for the known problems [7–10].

Load balancing is a technique used for balancing the load over several resources and links in order to eliminate congestion at mesh clients (lower level backbone of WMN), mesh routers (medium level backbone), GWs (upper level backbone), and paths between them. The GW acts as a potential bottleneck due to the huge increase in the traffic and limited link capacity. Hence, load balancing becomes a challenging task in WMN [11, 12]. Some GWs are affected by congestion problems, whereas the others are severely underutilized. Congestion has a negative effect on the network performance in terms of packet delivery ratio, aggregated network throughput, and end-to-end delay [20].

In multichannel WMN, channel assignment and GW selection are crucial numbers. Apart from interference, delay and channel quality metrics should be considered while selecting the GW. In Cross-layer design with optimal dynamic GW selection (CLC_DGS) [20], dynamic GW selection strategy is proposed in which the GWs are selected based on the queue length. Then the traffic is distributed among the selected GWs. Though this approach considers the capacity and delay constraints among the links, it does not consider the quality of the channels at the selected GWs. While assigning the channels to a node, the channel switching cost should be minimized. More discussions on other existing works are presented in the next section.

We propose to design a dynamic channel assignment and GW load balancing technique for multi-channel wireless mesh networks. The paper is organized as follows: Section 2 deals with the related literature. The details of DCAGS algorithms used for implementation are given in Section 3. The details of graphical representations and comparison are given in Section 4. Finally, Section 5 concludes the paper.

2 Related Works

Kumaravel et al. [2] has proposed a novel routing protocol on the basis of hybrid BAT algorithm and A* path finding algorithm. Discovery, path selection, and route maintenance are the three phases involved in this protocol. During path discovery phase, the shortest path between the GW and other nodes is found with the help of A* path finding algorithm in which more than five routes are discovered. During path selection, by considering load balancing using hybrid BAT algorithm based on path relinking algorithm, the best path will be selected for data transmission. During the joining of new nodes or node failures, nodes that are moving continuously in route are maintained via the other two phases.

Aljober et al. [5] has proposed a path mesh router-gateway load balancing model which is a multi-objective model for multicast load balancing optimization in WMN. This model minimizes the total cost of the network, path length, gateway load balancing, and path interference. With the help of a meta-heuristic method, this optimization problem is simultaneously solved.

Liu et al. [13] has proposed an efficient scheme for balancing the load among different Internet Gateways (IGWs) within a WMN. This scheme includes a traffic load calculation module and a traffic load migration algorithm. IGW can judge whether the congestion has occurred previously or will occur in the future with the help of a linear smoothing forecasting method. IGW will choose another available IGW with the lightest traffic load as the secondary IGW when it detects the occurrence of congestion. Some mesh routers are selected using the Knapsack algorithm. IGW informs those selected mesh routers (MPs) to change to the secondary IGW. By using a regression algorithm, MPs can return to their primary IGW.

Kapadia et al. [14] has proposed congestion-aware multipath routing protocol (EAOMDV-LB) for multi radio multiple interface WMN to estimate multiple paths using airtime congestion aware metric and perform load balancing by estimating queue utilization of multiple interfaces of a node. By diverting traffic all the way through congested area, the effective load balancing technique preserves data transmission on optimal path. Khaliq et al. [17] has proposed congestion avoidance hybrid wireless mesh protocol to provide localized re-routing based on congestion threshold with less overhead. By using CCNF received from the next hop neighbor, the re-routing decision is made by each node. This protocol does not add any overhead since the CCNF is already the design part of 802.11s.

F. Kaabi et al. [18] In multichannel WMN design, topology discovery, traffic identification, channel assignment and routing are essential. The traffic in WMNs is principally directed between nodes conjointly with the internet, however, we tend to believe that traffic also exists between nodes themselves. High-bandwidth applications need adequate network capability, therefore it is difficult to create a network providing such capability. So as to boost WMNs capability, a decent management of the obtainable frequencies is important. The concept of learning automata has been used for prediction. A distributed gateway selection algorithm is proposed to predict the dynamic environments. A new channel assignment scheme has been proposed to predict the network dynamics [21, 22]. A traffic-aware gateway selection scheme has been proposed in [25] in which genetic algorithm is used to assign priority to the nodes. Some of the works [23, 24] perform routing and channel assignment jointly. While the works [23, 24] concentrate on unitcast routing, the work [29] presents multicast routing. The work [27] jointly performs resource allocation and channel assignment. Interference-free or interference-aware channel assignment techniques have been proposed in [26, 28, 30].

All the above discussed works did not provide load balanced routing considering the channel quality. The channel selection was not related to the gateway selection. While allocating the channel and transmitting the data, congestion at the routers and gateways were not resolved which may greatly affect the performance. Hence, efficient channel assignment, gateway selection and load balanced routing has to be developed to solve the identified problems.

3 Dynamic Channel Assignment and Gateway Load Balanced Routing (DCAGLBR) Protocol

3.1 Overview

The design that dynamically changes the used approach supported message priority, to be able to maintain a lower power consumption if doable, whereas guaranteeing a lower end-to-end delay once required [31]. Once nodes traffic load exceeds sure threshold, dynamic channel assignment algorithms allow wireless nodes to change channels. However, the thresholds are nothing to estimate their performance. These estimations would not be precise due to Co Channel Interference (CCI) and adjacent channel interference (ACI) [28] notably with significant traffic loads in intense networks.

In this paper, dynamic channel assignment and GW load balanced routing protocol for multichannel WMN is presented as shown in Fig 1. In this protocol, the dynamic gateway selection method of [20] is extended by incorporating channel quality and switching cost along with queue length. Then a combined cost metric is determined incorporating these metrics. Then the GW having the minimum cost metric is selected by the source node. Then channels are fairly assigned in the network by the selected GW between itself and the mesh clients.

When a mesh client wants to transmit a data to its GW node, it selects a path with the minimum load based on the interface queue length. If congestion is detected at any intermediate node, the router detects the congestion based on the Exponentially Weighted Moving Average (EWMA) of the queue size. If the average queue size of the link is greater than a congestion threshold, then the link is said to be congested. To prevent the congestion at the GW nodes, each GW estimates the traffic load of the current interval and predicts the traffic load of the next interval using Hidden Markov Model (HMM). If congestion is predicted, then the GW informs the Mesh Access Point (MAP) to change to another GW using the dynamic GW selection process.

3.2 Estimation of Metrics

3.2.1 Network Interface Queue Length (IFQ)

The network Interface Queue Length (IFQ) stores the packets in the form of a stack to manage all incoming and outgoing packets. We set the limit of IFQ to the maximum number of packets that can be held by the queue.

3.2.2 Traffic Load estimation of GW

The traffic load at $GW_i\left(Y_i^{GW}\right)$ is estimated using the following equation:

$$Y_i^{GW} = \frac{N_{pr} * B_{avg} * 8}{c} \tag{1}$$

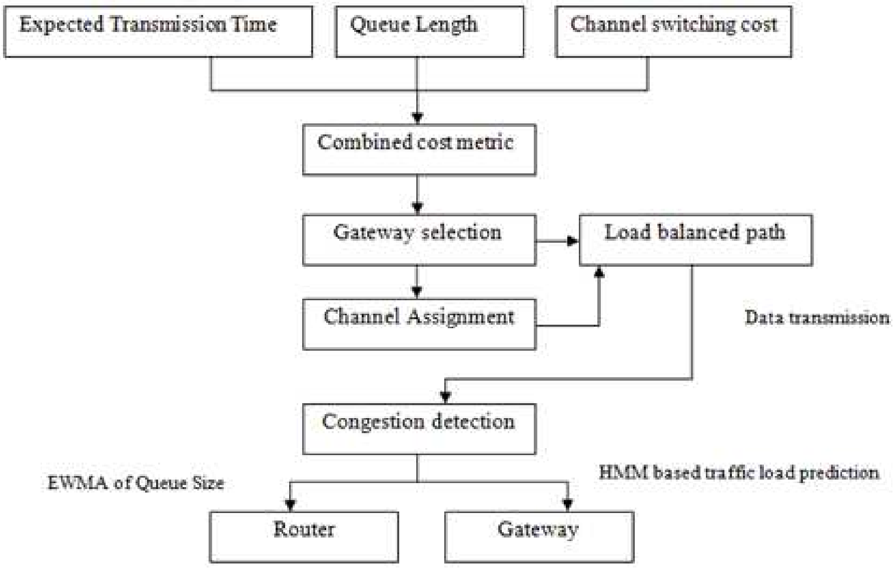

Fig. 1: Block diagram of the proposed protocol

where N_{pr} is the number of packets received by the GW node,
B_{avg} is the average size of the received data packets and
c is the length of the interval.

3.2.3 Queue Length

Let Q_i^{GW}(t) be the queue length of node i towards the GW at time slot t.

Then Q_i^{GW} at next time slot $(t+1)$ is computed using the following equation:

$$\underset{\substack{b\in T,\\ f:s(f)=ia\in T}}{Q_i^{GW}} (t+1) \leqslant \max[Q_i^{GW}(t) - \sum y_{GW}^{f} \cdot r_i^f(t) + \sum \mu_{ia}^{GW}(t)] \quad (2)$$

3.2.4 Channel Switching Cost

The Channel Switching Cost (CSC) for each channel k along GW is estimated as:

$$CSC = P(k) \cdot d \quad (3)$$

where $P(k)$ is the probability that a channel switching is required at channel k and d is the delay involved in switching between channels.

3.2.5 Expected Transmission Count

The Expected Transmission Count (ETC) for each link towards GW is estimated using the following equation:

$$ETC = \frac{1}{pd_r \cdot pd_f} \quad (4)$$

where pd_r and pd_f are the delivery ratio along reverse and forward directions, respectively.

3.2.6 Link Capacity

The Link Capacity (LC) for each link is computed using the following equation:

$$LC = \frac{S_{LP}}{d_i} \quad (5)$$

where S_{LP} is the size of the large packet and d_i is the delay.

3.2.7 Expected Transmission Time

The Expected Transmission Time (ETT) for each link towards GW is estimated using the following equation:

$$ETT = \frac{ETC \cdot p_{\text{size}}}{LC} \quad (6)$$

where p_{size} is the size of each data packet.

3.3 Gateway Selection Algorithm

The source S initially considers all the available GW in its surrounding to select the best GW for its data transmission based on the metrics: queue length, channel switching cost and ETT which are measured for each channel along the GW. Then a combined cost metric is determined by the S comprising these metrics. Then the GW having minimum cost metric is selected by the source node. This process is described in Algorithm 1.

The steps involved in the gateway selection phase are described in Algorithm 1.

Algorithm 1:

1. For each GW_j, $j = 1, 2, \ldots, k$
2. S estimates the next possible Q_i^{GW} using Eq. (2).
3. S estimates CSC for each channel along GW_j using Eq. (3).
4. S estimates ETC for each link towards GW_j using Eq. (4).
5. LC is estimated using Eq. (5).
6. Based on ETC and LC values estimated, S estimates ETT using Eq. (6).
7. After estimating these metrics, S generates a combined cost (CC) using the following equations:

$$CC_j = \alpha Q_i^{GW} + \beta \cdot CSC + \gamma .ETT$$
$$CC_j = \propto .Q_i^{GW} + \beta CSC + \gamma ETT \tag{7}$$

where α, β, γ are normalization constants whose sum = 1.
8. If $CC_j = \min(CC)$, then
9. GW_j is selected for handling data transmission.
10. End if
11. End For

3.3.1 Minimum Load based Route Establishment

The minimum load-based path establishment is similar to the multicast route establishment technique described in GLBM [16]. The current queue length values of nodes from mesh client towards their GW were aggregated and the path with the least aggregated queue length value is selected.

1. When the Mesh Client (MC) wants to obtain a data from its registered GW (GN_i), it broadcasts a route request (RREQ) to its neighbors.
$MC \xrightarrow{RREQ} N_i$

Table 1: Format of RREQ message

Source Node ID (ID_{src})	Destination Address (D_{add})	Q_i^{GW}

2. When N_i receives RREQ message, it adds its Q_i^{GW} value information into the packet header and rebroadcast the request again.
$N_i{*}\xrightarrow{RREQ+Q_i^{GW}}$
3. When GN_i receives the request message (RREQ) from various nodes, it verifies the aggregated Q^{GW} field in the packet header (Table 1).
4. GN_i then selects the path having the least aggregated Q^{GW} value, as the path from the GW to the MC.
5. If there is an entry with the same destination address, then GN_i sends route reply (RREP) message combining the routes from request receiver to GN_i and GN_i to MC. Otherwise, GN_i sends an error message to the receiver node to indicate the non-availability of the requested route.
6. When MC receives RREP, it updates the routing details and transmits a data to the receiver.
7. HMM-based Prediction of Traffic Load

3.3.2 Hidden Markov Model (HMM)

A hidden markov model is defined as a stochastic process of moving among states and a process of emitting an output sequence. However, the series of state transitions are hidden and observed only through the sequence of the emitted symbols. Mainly, it includes persistent finite-state Markov Chain, variables signifying the output and a distribution for every transition over the variable in the Markov Chain.
Let FS be the fixed state sequence of length L
Let HS be the set of hidden states
Let OS be the set of observation symbols per state
Let U be the state transition probability distribution
Let V be the observation symbol probability distribution in state j
Let π denotes the initial state distribution
The main elements of HMM are as follows:

1. Fixed state sequence of length L

$$FS = fs_1, fs_2, \ldots, fs_i \tag{8}$$

2. A number of hidden states

$$HS = \{Hs_0, Hs_1, \ldots, Hs_n\} \tag{9}$$

where n = number of hidden states in the system.
3. A set of observation probability distributions reflecting random variables or stochastic processes.

$$OS = \{Os_0, Os_1, \ldots, Os_n\} \tag{10}$$

4. The initial state distribution is illustrated below:

$$\pi = \{\pi_i\} \tag{11}$$

where π_i = probability of initiating in state i.
5. A transition probability distribution (U) based on the earlier state and indicates a new state after each time t,

$$U = \{u_{i,j}\} \tag{12}$$

$$u_{i,j} = \text{probability of moving from state } i \text{ to } j.$$
$$u_{i,j} = P[X_k = HS_j | X_{k-1} = HS_j] \tag{13}$$

6. Observation state probabilities are given by V :.

$$V = \{v_{j,k}\} \tag{14}$$
$$v_{j,k} = P[OS_k att | X_{k-1} = HS_j] \tag{15}$$

The entire model is precisely shown using the following equation:

$$\tau = (U, V, OS) \tag{16}$$

Each GW predicts the traffic load at the next interval using Hidden Markov Model (HMM). Initially the GW estimates the traffic load at the current interval using (1)

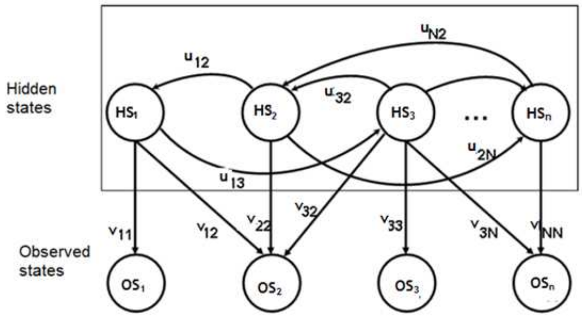

Fig. 2: Hidden markov model

and passes it to the HMM model to predict the traffic load at the next interval.

Where AB is taken as observation state OS, Observation probability (OS) for a given sequence FS is given as:

$$X(OS|FS,\delta) = \prod_{t=1}^{L} P(AB_t|n_t,\delta) = v_{n1}(AB_1) * v_{n2}(AB_2),\ldots,v_{nL}(AB_L) \quad (17)$$

The probability of the state sequence is given by:

$$P(FS|\delta) = \pi_{n1}, u_{n1}, u_{n2}, u_{n2n3}, \ldots, u_{nL-1nL} \quad (18)$$

Based on the above two Eqs. (5) and (6), the probability of observations is estimated:

$$P(OS|\delta) = \sum_{FS} P(OS|FS_1\delta)P(FS|\delta) = \sum_{n_1\ldots,n_L} \pi_{n1}v_{n1}(AB_1)u_{n1n2}v_{n2}(AB_2), \ldots, u_nL-1nL^V nL(AB_L) \quad (19)$$

In order to determine the single optimum state sequence for an observation sequence n_1, a Viterbi algorithm is used. The probability of the most probable timeslot is estimated using:

$$\alpha(i) = \max_{n_1,n_2,n_3,\ldots,n_{L-1}} P(n_1,n_2\ldots,n_L = HS_i,AB_1,AB_2\ldots,AB_t|\delta) \quad (20)$$

The extreme probable state is estimated using the following equation:

$$\overset{\wedge}{\underset{L}{n}} \arg \max_{1\leqslant i\leqslant FS} [\alpha_L(i)] \quad (21)$$

The sequence of states is initiated again as the pointer in every state. State sequence backtracking is given using the following equation:

$$\hat{n}_L = [\hat{\alpha}_{L+1}(n_{t+1}),t] = L-1, L-2, \ldots, 1 \quad (22)$$

where α = additional matrix of size $FS * L$
L = sequence length time.

α is introduced in Viterbi algorithm to estimate the bandwidth. This backtracking gives the required set of states.

3.4 Channel Assignment Algorithm

After the selection of the GW, the source node sends it data through channels assigned by the GW. The channel assignment process is performed in a timely manner, where each channel is assigned for data transmission by the GW. This process is described in Algorithm 2.

The steps involved in the channel assignment phase are described in Algorithm 2.

Notations used in Algorithm 2	
GW	Gateway
S	Source node
x	channel
RTR	Request To Receive message
T_{RTR}	RTR Timer
T_{BUSY}	Busy Timer
T_{back_off}	back off time

In this way, the channels are assigned to perform data communication between the nodes through the GW, such that each channel is allotted a specific time interval to perform data transmission to the available nodes. The channel assignment function is managed solely by the GW and the source nodes transmit its data through the channel during its turn. Thus, the channels are effectively assigned to perform data communication.

3.5 Congestion Detection

In congestion detection phase, the congestion occurring at both the routers and gateways along a path is detected and resolved. A mesh router detects the congestion state on its outgoing link using a simple thresholding scheme. The router maintains an Exponentially Weighted Moving Average (EWMA) of the queue size from link i to j [19].

The steps involved in the congestion detection phase are described in Algorithm 3.

Notations used in Algorithm 3	
R_i and R_j	Routers
MAP	Mesh Access Point
S	Source node
$Y_i^{GW}(t)$	Traffic load of GW_i at interval t
$Z_{i\to j}^{inst}$	Instantaneous queue size for link $i \to j$
$Z_{i\to j}^{avg}$	EWMA of the queue size for link $i \to j$
w_z	Weight value corresponding to EWMA
AR_i	incoming rate of the packets at i
OR_i	outgoing rate of packets from i to j
CN_{th}	Congestion threshold
RR	Revised data rate
CN_{on}	Congestion notification message

Algorithm 2:

1. The GWs in the network broadcasts RTR message to all the nodes along a channel x and initiates T_{RTR}.
2. When S receives the RTR message, it checks if the broadcasting GW is same as the selected GW.
3. If the broadcasting GW is not the selected GW, then S ignores the broadcast message.
4. If the broadcasting GW is the selected GW, then S responds to the RTR message by sending a RESPOND message to GW after T_{back_off}.
5. When GW receives the RESPOND message, it will check if the T_{RTR} has expired.
6. If T_{RTR} has expired, then GW ignores the message.
7. If T_{RTR} has not yet expired, then it will broadcast a BUSY message to prevent other 1 hop nodes on x from transmitting.
8. When GW broadcasts the BUSY message, it simultaneously initiates T_{BUSY} to check the utilization of x.
9. When S receives the BUSY message, it starts transmitting its data packets through x.
10. If S completes transmitting its data packets before the expiration of T_{BUSY} then it sends a COMPLETED message to GW and stops its data communication.
11. When GW receives the COMPLETED message, it assigns the next idle channel for data communication.
12. If S does not complete its data transmission even after T_{BUSY} expires, then it will send an EXPIRED message to i and terminates the data communication by disconnecting the channel.
13. When i receives the EXPIRED message, it will stop the data transmission.
14. Then the GW will assign another channel for transmission.

Algorithm 3:

1. R_i estimates $Z^{avg}_{i\to j}$ for every outgoing link $i \to j$ as described in [19]

$$Z^{\text{avg}}_{i\to j} = (1-w_z) * Z^{\text{avg}}_{i\to j} + w_z * Z^{\text{inst}}_{i\to j} \quad (23)$$

$$Z^{\text{inst}}_{i\to j} = \frac{ARi}{oRi} \quad (24)$$

2. If $ZZ^{\text{avg}}_{i\to j} > CN_{th}$, then
3. R_i detects that link $i \to j$ is congested
4. R_i determines RR
5. R_i transmits a CN_{on} with RR to source S
6. End if
7. If S receives RR, then
8. S adjusts its sending rate based on RR
9. End if
10. Each GW_iestimates $Y_i^{GW}(t)$ using (1)
11. GW_i predicts $Y_i^{GW}(t+1)$ using HMM
12. If $Y_i^{GW}(t+1) > CN_{th}$, then
13. GW_i informs MAP to change to another GW
14. Alternates GW is selected using the dynamic GW selection process
15. End if

Table 2: Simulation parameters

Number of mesh clients	4, 6, 8, 10 and 12
Area Size	1300×1300 m
MAC protocol	802.11
Simulation Time	100 seconds
Traffic Source	Constant Bit Rate (CBR)
Data sending rate	250 kbps
Number of Channels per node	1 to 5
Propagation	FreeSpace Model
Antenna	Directional Antenna

In this algorithm, when the average queue size of the link is greater than a congestion threshold CN_{th}, then the link is said to be congested. When the router R_i detects that the link i→j is congested, it transmits the congestion notification message to the source by including the revised data rate field. When the source receives this congestion notification message, it adjusts its data sending rate based on the revised data rate. If the predicted traffic load at the gateway (using HMM) along the route is greater than CN_{th}, then congestion is detected. Then the GW informs the Mesh Access Point (MAP) to change to another GW using the dynamic GW selection process.

4 Simulation Results

4.1 Simulation Parameters

The proposed DCAGLBR protocol is simulated in NS2 and compared with GLBM [16], WCP [19] and GSCM [24] protocols. The performance of the protocols is evaluated in terms of packet delivery ratio, packet drop, throughput and delay. The simulation parameters used in the simulation are summarized in Table 2.

4.2 Results & Analysis

4.2.1 Varying the mesh clients

The number of mesh clients is varied from 4 to 12 per domain.

Fig. 3 shows the delay measured for DCAGLBR, WCP, GSCM and GLBM protocols when the nodes are varied. As we can see from the figure, the delay of DCAGLBR increases from 27.18 to 32.7 ms, the delay of WCP increases from 32.05 to 35.88 ms and the delay of GLBM increases from 36.7 to 39.6 ms. And the delay of GSCM increases from 38.2 to 42.9. Since DCAGLBR reduces the delay due to congestion and routing faults, the delay of DCAGLBR is 15% lesser when compared to WCP and 23% lesser when compared to GLBM and 5% lesser when compared to GSCM.

Fig. 4 shows the delivery ratio measured for DCAGLBR, WCP and GLBM when the nodes are varied.

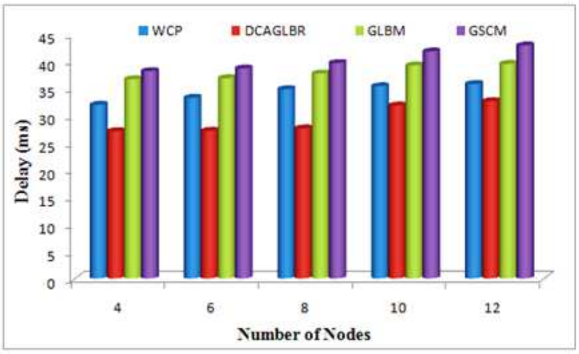

Fig. 3: End-to-end delay for varying nodes

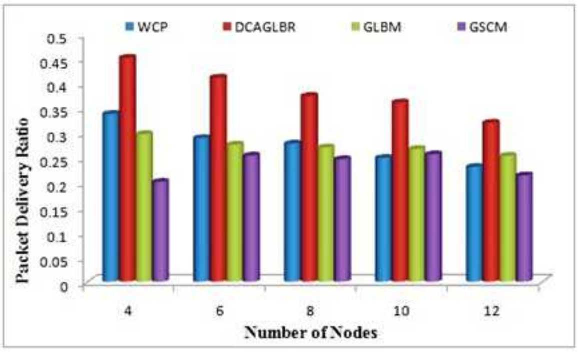

Fig. 4: Packet delivery ratio for varying node

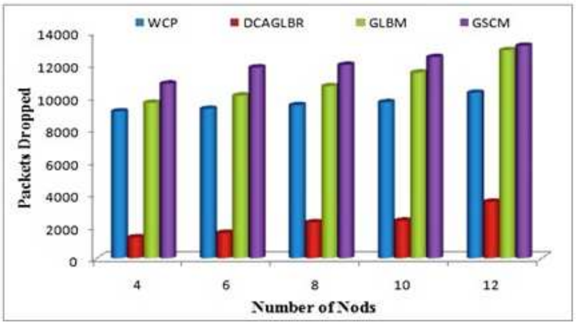

Fig. 5: Packet drop for varying nodes

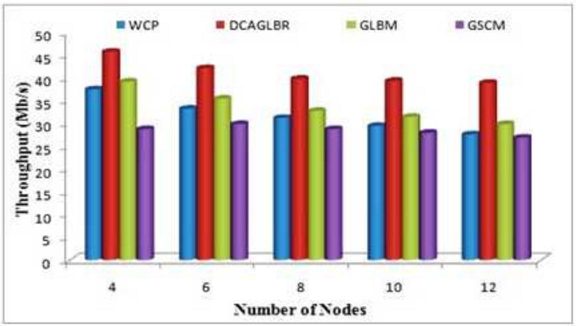

Fig. 6: Throughput for varying nodes

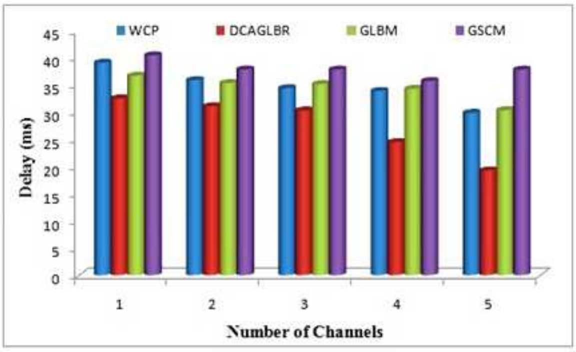

Fig. 7: End-to-end delay for varying channels

As we can see from the figure, the delivery ratio of DCAGLBR decreases from 0.45 to 0.32, the delivery ratio of WCP decreases from 0.33 to 0.23 and the delivery ratio of GLBM decreases from 0.29 to 0.25 and the delivery ratio of GSCM increases from 0.20 to 0.21. Since DCAGLBR reduces the packet drops due to congestion and bad channel conditions, the delivery ratio of DCAGLBR is 28% higher when compared to WCP and 28% higher when compared to GLBM and 14% higher than GSCM. Table 3 contains the simulated results obtained: end-to-end delay and packet delivery ratio with respect to varying the number of nodes.

Fig. 5 shows the packet drop measured for DCAGLBR, WCP and GLBM when the nodes are varied. As we can see from the figure, the drop of DCAGLBR increases from 1289 to 3488 packets, the packet drop of WCP increases from 9072 to 10219 packets and the packet drop of GLBM increases from 9601 to 12850 packets and the drop of GSCM increases from 10785 to 13121. Since DCAGLBR reduces the packet drops due to congestion and bad channel conditions, the packet drop of DCAGLBR is 77% lesser when compared to WCP and 80% lesser when compared to GLBM and 9% lesser when compared to GSCM.

Fig. 6 shows the throughput measured for DCAGLBR, WCP and GLBM when the nodes are varied. As we can see from the figure, the throughput of DCAGLBR decreases from 48.7 to 38.9 Mb/s, throughput of WCP decreases from 37.45 to 27.58 Mb/s and throughput of GLBM decreases from 39.14 to 29.83 Mb/s and the throughput of GSCM decreases from 28.6 to 26.8 Mb/s. Since DCAGLBR balances the load and reduces channel switching cost, the throughput of DCAGLBR is 23% higher when compared to WCP and 18% higher when compared to GLBM and 15% of higher than GSCM. The simulated results: packets dropped and throughput is obtained with varying the number of nodes shown in Table 4.

4.2.2 Varying the Number of Channels per Node

The number of channels per node is varied from 1 to 5.

Table 3: Simulation results obtained delay and packet delay ratio with varying number of nodes

Nodes	End-to-end delay (ms)				Packet Delivery Ratio			
	WCP	DCAGLBR	GLBM	GSCM	WCP	DCAGLBR	GLBM	GSCM
4	32.05	27.18	36.75	38.24	0.3387	0.4521	0.298	0.2017
6	33.34	27.25	36.95	38.74	0.29	0.4122	0.2768	0.2548
8	34.91	27.69	37.81	39.74	0.2788	0.375	0.271	0.2475
10	35.46	31.92	39.3	41.87	0.25	0.362	0.268	0.2574
12	35.88	32.7	39.6	42.98	0.2319	0.321	0.2542	0.2147

Table 4: Packets dropped and throughput (Mb/s) with varying number of nodes

Nodes	Packets Dropped				Throughput (Mb/s)			
	WCP	DCAGLBR	GLBM	GSCM	WCP	DCAGLBR	GLBM	GSCM
4	9072	1289	9601	10785	37.45	45.71	39.14	28.74
6	9225	1568	10048	11784	33.21	42.11	35.41	29.85
8	9450	2220	10628	11942	31.18	39.78	32.73	28.75
10	9634	2321	11465	12425	29.44	39.32	31.43	27.94
12	10219	3488	12850	13121	27.58	38.88	29.83	26.87

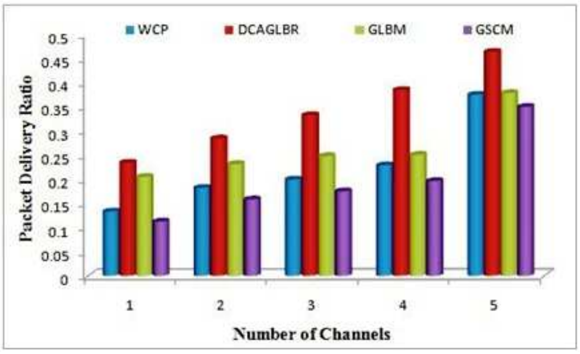

Fig. 8: packet delivery ratio for varying channels

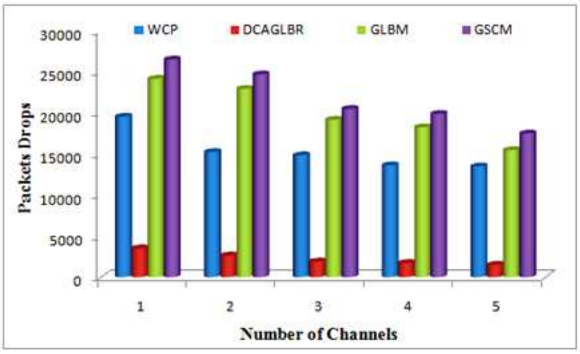

Fig. 9: packet drop for varying channels

Fig. 7 shows the delay measured for DCAGLBR, WCP and GLBM when the channels are varied. As we can see from the figure, the delay of DCAGLBR decreases from 32.55 to 19.28 ms, delay of WCP decreases from 39.11 to 29.89 ms and the delay of GLBM decreases from 36.7 to 30.38 ms and the delay of GSCM decreases from 40.7 to 38.7 ms. Since DCAGLBR reduces the delay due to congestion and routing faults, delay of DCAGLBR is 21% lesser when compared to WCP and 20% lesser when compared to GLBM and 9% of lesser when compared to GSCM.

Table 5 contains the simulated results on end-to-end delay and packet delivery ratio with respect to varying the number of channels and Fig. 9 shows the delivery ratio measured for DCAGLBR, WCP and GLBM when the channels are varied. As we can see from the figure, the delivery ratio of DCAGLBR increases from 0.23 to 0.46, delivery ratio of WCP increases from 0.13 to 0.37 and the delivery ratio of GLBM increases from 0.20 to 0.37 and the delivery ratio of GSCM increases from 0.11 to 0.34. Since DCAGLBR reduces the packet drops due to congestion and bad channel conditions, the delivery ratio of DCAGLBR is 36% higher when compared to WCP and 22% higher when compared to GLBM and 27% higher when compared to GSCM.

Fig. 8 shows the packet drop measured for DCAGLBR, WCP and GLBM when the channels are varied. As we can see from the figure, the packet drop of DCAGLBR decreases from 3524 to 1521 packet, packet drop of WCP decreases from 19536 to 13488 packets and packet drop of GLBM decreases from 24134 to 15453 packets and the drop of GSCM decreases from 26472 to 17482. Since DCAGLBR reduces the packet drops due to congestion and bad channel conditions, the packet drop of DCAGLBR is 86% of lesser when compared to WCP and 89% lesser when compared to GLBM and 8% lesser when compared to GSCM.

Fig. 10 shows the throughput measured for DCAGLBR, WCP and GLBM when the channels are varied. As we can see from the figure, the throughput of DCAGLBR increases from 37.58 to 45.89 Mb/s, throughput of WCP increases from 34.32 to 42.15 Mb/s and the throughput of GLBM increases from 37.55 to 42.67 Mb/s and the throughput of GSCM increases from 32.6 to 40.2. Since DCAGLBR balances the load and reduces channel switching cost, the throughput of

Table 5: Simulation results obtained delay and packet delay ratio with varying number of channels

Channels	End-to-End Delay (ms)				Packet Delivery Ratio			
	WCP	DCAGLBR	GLBM	GSCM	WCP	DCAGLBR	GLBM	GSCM
1	39.11	32.55	36.7	40.47	0.1332	0.2341	0.2048	0.1125
2	35.9	31.1	35.36	37.87	0.1822	0.2843	0.2312	0.1584
3	34.42	30.34	35.18	37.84	0.1995	0.3326	0.2478	0.1752
4	33.9	24.49	34.3	35.74	0.2288	0.3844	0.2503	0.1963
5	29.89	19.28	30.38	37.84	0.3748	0.4636	0.3781	0.3497

Table 6: Simulation results obtained packets dropped and throughput (Mb/s) with varying number of channels

Channels	Packets Dropped				Throughput (Mb/s)			
	WCP	DCAGLBR	GLBM	GSCM	WCP	DCAGLBR	GLBM	GSCM
1	19536	3524	24134	26472	34.32	37.58	37.55	32.45
2	15236	2657	22911	24681	37.28	39.45	38.43	34.85
3	14838	1920	19156	20475	37.44	41.67	39.11	35.14
4	13619	1743	18241	19874	39.81	44.38	41.25	38.64
5	13488	1521	15453	17482	42.15	45.89	42.67	40.65

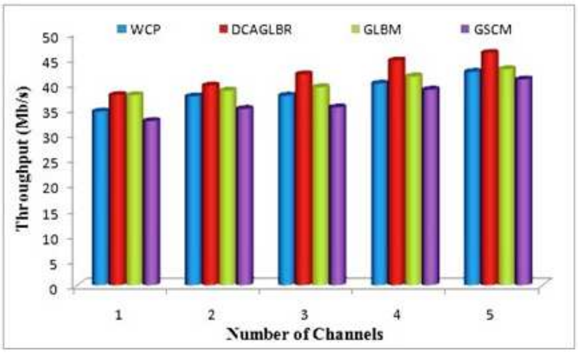

Fig. 10: Throughput for varying channels

DCAGLBR is 9% higher when compared to WCP and 5% higher when compared to GLBM and 9% higher than GSCM and also the simulated results for packets dropped and throughput values are shown in Table 6.

5 Conclusion

In this paper, dynamic channel assignment and GW load balanced routing protocol for multichannel WMN is proposed. In this protocol, the GW having the minimum cost metric is dynamically selected by the source node, followed by channel assignment. In GW load balanced routing, the GW selects a path with the minimum load based on interface queue length. Congestion is detected at intermediate routers based on queue size and congestion is detected at GW by predicting the traffic load of the next interval using HMM. The proposed DCAGLBR protocol is simulated in NS2. By simulation results, it has been shown that the DCAGLBR protocol reduces the packet drop and delay and improves the throughput when compared to existing techniques.

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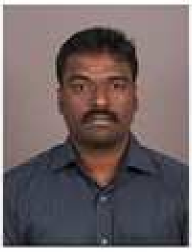

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