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Abstract — As an emerging technology, wireless mesh networks are making significant progress in the area of wireless networks in recent years. Routing in Wireless Mesh Network (WMN) is challenging because of the unpredictable variations of the wireless environment. Traditional mechanisms have been proved that the routing performance would get deteriorated and ideal metrics must be explored. Most wireless routing protocols that are currently available are designed to use a single channel. The available network capacity can be increased by using multiple channels, but this requires the development of new protocols specifically designed for multi-channel operation. In this paper, we propose Neighbourhood load routing metric in single channel mesh networks and also present the technique to utilize multiple channels and multiple interfaces between routers for communication. The traditional routing metrics Hop Count and Weighted Cumulative Expected Transmission Time (WCETT) are used in routing. We compare performance of AODV-HOP, WCETT and NLR routing metrics in singlechannel and multichannel environment by considering throughput and end to end delay performance metrics. Our results show that NLR performs better in singlechannel environment.

Keywords*— Routing Metric, WMN, AODV, WCETT, ETX, ETT, WCETT,NLR*

I. INTRODUCTION

Wireless Mesh Network (WMN) [1] is a promising technology to offer a list of benefits in constructing next generation networks in a sizable geographic area. It brings a lot of benefits to build wireless metropolitan networks as the most outstanding characteristic of WMNs is low cost. It is because instead of using optical fibre cable, wireless radios are applied in WMNs which have been already deployed to build wireless broadband network in some newly developing areas worldwide and isolated islands. A WMN combines the characteristics of both fixed network and MANET. The communication inside a WMN is similar to MANET, client nodes are self-configured and self-organized where the routes are selected by using certain routing algorithm and each client node has to relay other's packets. For accessing backbone internet, the packets are forwarded through internet gateway to the fixed network by fixed cable links.

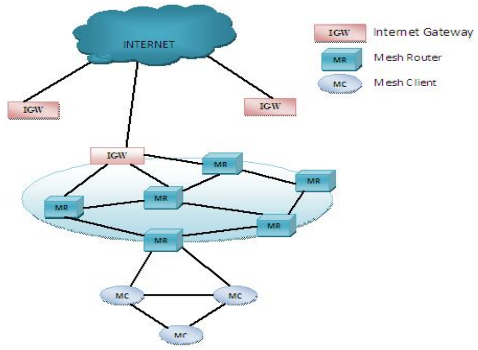

Figure 1: The network structure of a typical WMN

WMNs can be divided into three main types: Infrastructure, Client, and Hybrid. In an *Infrastructure* WMN, Mesh Clients gain access to each other or to the backhaul network through Mesh Routers and are not actively involved in routing and forwarding of packets. Thus, all Mesh Clients gain access to Mesh Routers via a single wireless hop. In *Client* WMNs, Mesh Clients communicate with each other directly, without involving any Mesh Routers. A Client WMN is essentially a pure multi-hop mobile ad-hoc wireless network. A *Hybrid* WMN combines the connectivity pattern of both the Infrastructure and Client WMNs as shown in Figure 1. In these networks, both Mesh Clients and Mesh Routers are actively involved in routing and forwarding of packets and Mesh Clients can access the wireless backhaul network via multiple client hops. The routing capabilities of clients provide improved connectivity and coverage inside the WMN. The hybrid architecture provides full advantage of the WMN.

A routing metric is implemented in the routing protocol to judge the superiority of a route over other alternate ones. The routing metrics cover a set of routing constraints such as bandwidth, network delay, path length, load balancing, reliability, and communication cost and so forth. In addition, the improvement of one aspect normally results in all other aspects. As mentioned in [1], new routing metrics are required to examine and improve the performance of WMNs in dealing with more constraints. Hence, the design of routing metrics is very important to improve the overall performance of WMNs and MANETs.

For meeting the ever-increasing throughput demands of applications, it is necessary to utilize the entire available spectrum. Multiple channels have been utilized in infrastructure-based networks by assigning different channels to adjacent access points, thereby minimizing interference between access points. However, typical multi-hop wireless network configurations have used a single channel to ensure all nodes in the network are connected. For the full utilization of available channels, it is desirable to have different nodes communicating (in parallel) on different channels. However, when using multiple channels, two adjacent nodes can communicate with each other only if they have at least one interface on a common channel. Therefore it may be necessary to periodically switch interfaces from one channel to another to enable different nodes to communicate with each other. Furthermore, interface switching may have to be carefully coordinated to allow any adjacent pair of nodes to communicate with each other.

Load balancing of WMN becomes a hot topic as it provides better QoS provision in offering high throughput, high packet delivery ratio, low delay, and low jitter. Therefore authors are proposing multi-channel assignment for WMN and usage of WCETT metric in routing.

The remainder of this paper is organised as follows. Section II examines routing metrics and usage of multiple channel assignment, and section III describes the requirements for multichannel assignment and examines performance of HOP-COUNT and WCETT routing metrics in multi channel environment. Section IV presents the simulation results and performance evaluation. Section V concludes our work.

II. RELATED WORK

In this section, we describe series of existing routing metrics, and then show how they work, focusing on their abilities to satisfy the requirements of WMN.

HOP COUNT: It is widely used in existing protocols such as AODV [13], DSR [14], and DSDV [15]. It helps a routing protocol to avoid long transmission paths in finding the routing path with the minimum distance, i.e. hop number. Other issues such as interference, transmission rate, and packet loss ratio are not considered in this routing metric. Therefore, *HOP COUNT* may result in poor performance in some network environments.

***LOAD COUNT* [9] [10]:** It is a load balancing metric for wireless networks

$$\text{Load \_Count} = \sum_{i=1}^{n} Load_i$$

where $Load_i$ is the traffic load on a node i which is normally captured by using IFQ length. The IFQ (Network Interface Queue) is a drop-tail buffer at the MAC layer of 802.11 radios, which contains outbound frames to be transmitted by the physical layer where the size of IFQ is calculated as the number of remaining packets in the buffer.

***Expected Transmission Count* (*ETX*):** It is a metric to estimate the expected number of MAC layer transmissions for the wireless links and measure the packet loss rate which is proposed by De Couto et al. [11] [12]. A node sends out probe packets to all its neighbour nodes every second. When a neighbour node receives probes, it increments the amount of received packets and calculates the loss rate of packet every 10 seconds. The weight of a route is the sum of the *ETX* of all links along the path. The possibility of successful packet transmission from source *a* to destination *b* in a wireless link is: $p = (1- pf) \times (1- pr)$ Then ETX can be achieve as

$$\text{ETX} = \sum_{k=1}^{\infty} kp^k\, 1 - p^{k-1}$$

Where *pf* is the probability of successful forwarded packets and *pr* denotes the probability of successful received packets. The advantages of *ETX* are the reduced probing overhead and non self-interference as the delay is not measured. However, *ETX* cannot measure the cause of data size in the delivery ratio and it doest not consider the transmission rate. Furthermore, unicast probing of *ETX* is not accurate as differences between broadcast and unicast.

ETT (Expected Transmission Time)* [18]*: Though the expected transmission count matters, the time taken for transmission affects throughput, so ETT was developed and selected as link metric. ETT captures the data rate at which packets are transmitted, means the time required for successful sending of one data packet. In other words, ETT, as metric that improved ETX method, is a method of calculating transmission expected value in MAC layer by reflecting link bandwidth and packet size

$$ETT = ETX \times S \quad (2)$$

'*S*' stands for data packet size, and 'R' the data transmission rate of that link. ETT produces accurate wireless link quality by reflecting transmission rate, but cannot reflect other important problems like protocol overhead and inter-flow interference.

***Weighted Cumulative ETT* (*WCETT*):** It is also proposed by Draves et al [16] and it considers the multi-radio nature of the WMNs in two components: the total transmission time along all hops in the WMN and the channel diversity in the path. The *WCETT* of a path *p* is

$$\text{WCETT (r)} = (1-p)ETT_i + P \underbrace{max}_{i \le j \le k} X_j$$

where p is a parameter, $0 \le p \le 1$. And path r uses X_j number of times of channel j. Therefore, $P \underbrace{max}_{i \le j \le k} X_j$ denotes the maximum number of times that the same channel j is used along a path. Although it captures the intra-flow interference of a path with measuring the channel assignment time, it does not consider the inter-flow interference. Thus, traffic flows may be routed to the dense area by *WCETT*.

One more important problem of the *WCETT* is that it is not isotonic which generates a forwarding loop while chosen a path

III. MULTIPLE CHANNELS AND MULTIPLE INTERFACES

In this section we study the use of multi interface and multi channel in wireless networks.

Many researchers have proposed the use of multiple channels and multiple interfaces for ad-hoc wireless networks [7]. However, we have studied P. Kyasanur's and N. H. Vaidya's interface assignment scheme in [2] for our implementation, as this approach is more flexible and versatile among others. Below we present a brief comparison between various related work and [2].

For instance, A. Raniwala, K. Gopalan, and T. Chiueh propose the centralized channel assignment and routing solution in [3]. Unlike this solution that is designed for use in static networks where traffic is directed towards specific gateway nodes, the approach in [2] allows any node to communicate with any other. Additionally, the approach in [3] expects stationary nodes and traffic load on every link, since this information is used to assign interfaces and compute routes. Oppositely, the solution in [2] does not need this information and thus is more suitable for ad-hoc networks involving mobile nodes.

Next, S. Wu, C. Lin, Y. Tseng, and J. Sheu propose a MAC layer solution in [4] that requires two interfaces: one for control, therefore assigned to a common channel; the other for data exchange, thus is switched among the remaining channels. Also, R. Maheshwari, H. Gupta, and S. R. Das propose new MAC protocols for multi-channel operation in wireless ad-hoc and mesh networks in [5]. The aforementioned two proposals all require changes to the existing IEEE 802.11 standard. On the contrary, the approach in [2] can be implemented using existing IEEE 802.11 wireless network interface cards.

Finally, paper [6] proposes a new routing metric called Weighted Cumulative Expected Transmission Time (WCETT), for multi-channel ad-hoc networks. WCETT ensures channel diverse routes are selected by assuming the number of interfaces per node is equal to the number of channels used by the network. In contrast, the *interface switching* technique proposed in [2] can allow the number of interfaces to be smaller than the number of available channels, while still manages to utilize all the channels.

IV. PROPOSED WORK

A. Multichannel Assignment

In this section we present all the requirements that we would like to fulfill with our development, and we also enumerate the working assumptions that we have made.

Figure 2 presents a high-level architecture of the modified *MobileNode* with multi-channel support. Each node can have as many instances of the link layer, ARP, interface queue, MAC, network interface and channel entities as the number of interfaces it has. One can imagine that each instance actually represents a wireless network interface. Thus, this design scheme emulates the fact that our multi-channel multi-interface ad-hoc network implementation will not require any modification to existing IEEE 802.11 hardware.

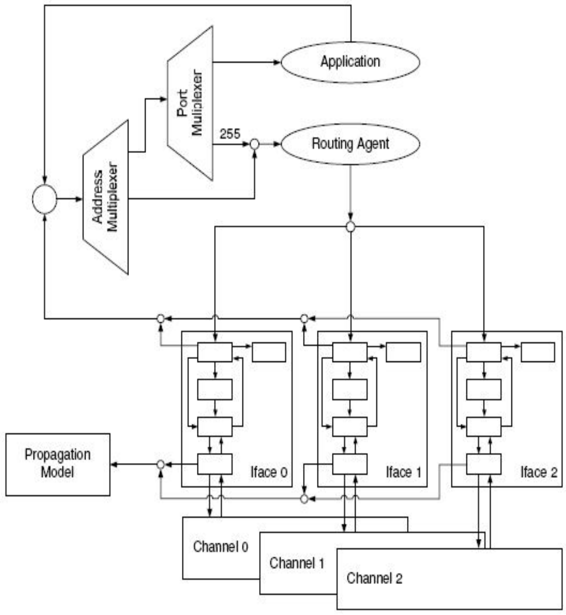

Figure 2: Mobile Node Architecture with Multi-channel support

As can be observed, most legacy operations of ns-2 are still preserved. Incoming traffic arrives through the corresponding channel and travel through the different components in ascending order then eventually merges to a single point at the address multiplexer. For outgoing traffic, the determination of selecting which interface to pass the data packets is to be handled by the routing agent. In other words, modifications will be required in implementing the routing agent to add the intelligence of selecting the appropriate interface.

In addition, the number of channels used in a single simulation could also be parameterized and nodes should be able to randomly connect to a subset of the defined wireless channels, thus giving a complete flexibility to the user. We understand that this level of flexibility, that needs to be accomplished from the scenario script, would be really important so as to evaluate different types of situations.

In addition, our intention is that the modified model could be used with any of the existing or new routing agents but it would also be nice being able to maintain the legacy behaviour of the simulator, so that already existing scripts would still be valid.

Requirements:

1. The number of channels in a particular scenario should be modifiable.
2. The number of interfaces per node is variable, and do not need to be the same for all nodes within a single scenario.
3. Each node within the same scenario could connect to a different number of channels (of the ones that had been previously defined).
4. Routing agents may take advantage of the modified model, but legacy operation of the simulator must be preserved, so as to ensure backwards compatibility.

B. Neighbourhood Load Routing

Problem description: In a WMN, the traffic may not be distributed evenly as some nodes are under light traffic load (transmitting or receiving a small amount of packets), while other nodes are under heavy traffic load (transmitting or receiving a large amount of packets). The problem of uneven traffic distribution caused overloaded traffic, is also defined as a load balancing problem.

To overcome centre node load balancing problem, the traffic load is supposed to be distributed evenly. In other words, the main objective that must be achieved is to keep the loads over different nodes comparable or even relatively equal. In an attempt to achieve this aim, our approach in this study consists of three stages. Firstly, the packets should travel on the lowest traffic load path instead of the shortest path. Secondly, a heavy loaded node should not be involved in forwarding packets. Thirdly, by reducing the interference of the network, the transmission waiting time of the packets decreases, thus, the overall traffic load of all nodes are reduced. Therefore, our proposal optimizes the traffic load distribution and reduces interference simultaneously.

In this section, we describe QoS-aware load balancing routing metric, namely, Neighbourhood Load Routing metric (NLR)[20]. It measures the average load of each neighbourhood and aim to bypass the busy neighbourhood instead of only bypassing the busy node by using LOAD COUNT routing metric.

Moreover, in a heavy loaded neighbourhood, extra traffic on one node generates interference to all its neighbourhood nodes and the transmission of packets in these nodes can be deferred, and then more packets are waiting in the IFQ.

To solve the above problem, NLR is used to check the average value of the neighbourhood load of a link which is:

$$NLR = \sum_{i=1}^{k} \frac{Load_i^n}{b_i^n} \qquad n = \frac{t_r}{d_{avg}}$$

where n is the interference radius of neighbourhood in hop number; tr denotes the transmission range), and d_{avg} is the average distance between two one-hop nodes. $Load^i_n$ denotes the average load of a neighbourhood of node i with radius n hops and bin is the average transmission rate of this neighbourhood. Hence, unlike the existing routing metrics, NLR considers three aspects in selecting a path, which are current IFQ length (packet size), neighbourhood interference, and neighbourhood bandwidth.

V. RESULT ANALYSIS

We use the NS-2 simulator [17] to evaluate the performance of AODV, *WCETT* and NLR. The simulation experiments aim to evaluate the performance of *NLR* in providing within the context of QoS provision of WMN. In our experiments, we compare *HOP COUNT,WCETT and NLR* in singlechannel WMN and also compare HOP COUNT and WCETT in multichannel WMN.

Two performance metrics are used which are *average throughput*, *average end-to-end delay* in the experiments. The *average throughput* calculates the capability of the network to accommodate traffic/messages. The *average end-to-end delay* is the average time a packet travels from a source to a destination.

In our simulation model the transmission range is 240m and simulation area extends up to 1000×1000m. Traffic source is FTP, and for each FTP session, the packet size is 1500 bytes and interval rate of 0.008 seconds. Following table shows the simulation parameters required to analyze the performance of WMN supporting single-channel and multi channel assignment.

Simulation Time	*80 seconds*
Simulation Area	*1000×1000m*
Propagation Model	*Two ray ground radio propagation*
Antenna Model	*Antenna/Omni Antenna*
Transmission Range	*240m*
Packet Size	*1500 bytes*
Interval Time	*0.008 seconds*
Address Type	*Hierarchical*
Channel Type	*Channel/Wireless Channel*
Number of Nodes	*10,20,30,40,50*

Table: Simulation Model

The following figures (namely Figure 3 and 4) shows the comparison of aodv-hop, wcett and NLR routing metrics by varying number of nodes from 10 to 50 in single-channel WMN using performance metrics average throughput and average end-to-end delay.

We can clearly see that *NLR* has distinguished performance in single channel topology WMNs compared to other routing metrics.

WCETT ranks the second place in *average ethroughput* and *AODV-hop* achieves the lowest, where as *NLR* is in the first place of examining of average throughput performance metric.

Aodv-hop and *wcett* suffer high communication time in delay while *NLR* scores the first place in *average end-to-end delay.*

To sum up the simulation results, we can cleary say that in single channel WMNs, NLR achieves high throughput than traditional hop-count and wcett routing metrics. The average end-to-delay is very high in aodv-hop and wcett, whereas NLR has low end-to-end-delay

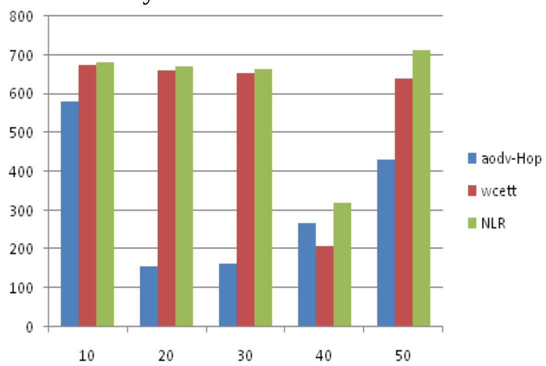

Figure 3: Average throughput in Singlechannel WMN

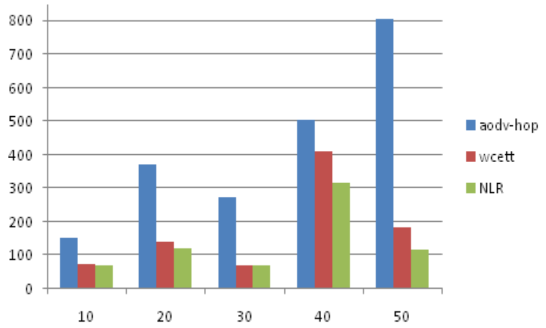

Figure 4: Average end-to-end delay in Singlechannel WMN

The following figures (namely Figure 5 and 6) shows the comparison of aodv-hop, and wcett routing metrics by varying number of nodes from 10 to 50 in multichannel WMN using performance metrics average throughput and average end-to-end delay.

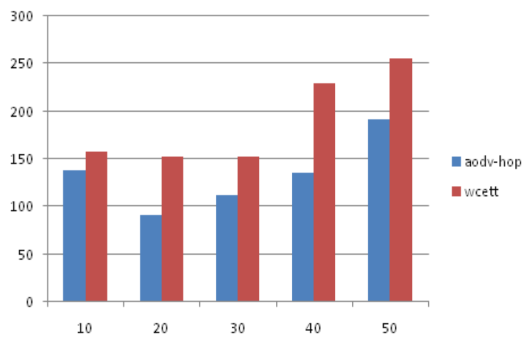

Figure 5: Average throughput in multichannel WMN

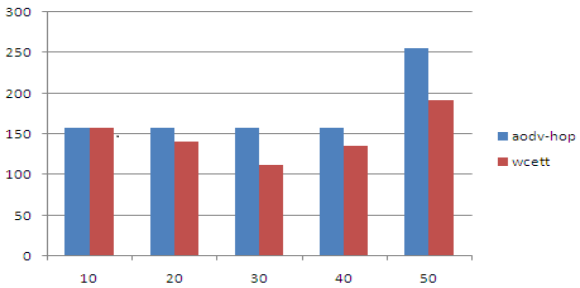

Figure 6: Average end-to-end delay in multichannel WMN.

From these figures, we can say that, network with multiple channel support has high throughput, and low delay than the single channel network. Hence, we are increasing the overall performance of the network in terms of average throughput, and low average end-to-end delay.

VI. CONCLUSION

WMN needs multiple hop communication. Hence the nodes in WMN network especially, the Mesh Routers should have multiple channels. Here we have a routing protocol AODV and WCETT to support multiple channel interfaces for Mesh routers. In the simulation, we implement *NLR* in NS-2, and compare them with *HOP COUNT* and WCETT and the results show that *NLR* attains the lowest *average end-to-end delay* and highest *average throughput* in single-channel WMNs. This fully proves NLR outperforms other routing metrics in communication cost and capability to offer high standard QoS provision. As a future work, we plan to convert NLR to multichannel routing metric.

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