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Full Length Research Paper

A load balancing interference aware routing metric (LBIARM) for multi hop wireless mesh network

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It is a well-known fact that routing metrics play a crucial part in the performance of wireless mesh networks (WMN). When routing protocols are implemented, the routing metrics are assigned to different paths. It calculates the best path to predict the best routing path. They are integrated in routing protocols to improve WMNs efficiency in terms of reliability, latency, throughput, error rate and cost. This paper addresses inter-flow interference, intra-flow interference and load balancing problem in multi hop WMNs. We have presented a new load balancing interference aware routing metric (LBIARM) that captures intra-flow interference, inter-flow interference and traffic load. The performance of LBIARM was then evaluated by comparing it with weighted cumulative expected transmission time metric (WCETT) using grid topology. OPNET Modeler 16.1 PL1 was used as a simulation tool for implementation.

Key words: Wireless mesh network, routing metric, OPNET.

INTRODUCTION

Wireless mesh network (WMN) (Akyildiz and Wang, 2005) is a promising wireless technology for several emerging and commercially interesting applications like broadband home networking, community and neighborhood networks, coordinated network management and intelligent transportation systems. It is gaining significant attention as a possible way for Internet service providers (ISPs) and other end-users to establish robust and reliable wireless broadband service access at a reasonable cost. They are now being seen as last few miles connectivity. Different from traditional wireless networks, WMNs are dynamically self-organized and self-configured. In other words, the nodes in the mesh network automatically establish and maintain network connectivity. This feature brings many advantages for the end-users, such as low up-front cost, easy network maintenance, robustness and reliable service coverage. Mesh networks can be seen as one type of mobile ad hoc network (MANET), but the later has to deal with problems introduced by the mobility of the nodes and the lack of infrastructure (Chlamtac et al., 2003). In WMN, the components can all connect to each other via multiple hops, and the backbone nodes generally are not mobile, or support little mobility. Figure 1 shows wireless mesh architecture.

In IEEE 802.11 mesh networks, there are two critical factors hampering performance. They are interference from simultaneous wireless transmission and load balancing. WMNs usually have poor throughput due to the signal interference. When the hops to gateways become large, this problem becomes severe. The foremost requirement of WMNs is high throughput, especially for the envisioned applications such as community and neighborhood networking, broadband home networking and backhaul networking for local and metropolitan areas. A wireless link bandwidth is shared among neighboring nodes. So a flow through wireless link causes two types of interference which affect the throughput of multi hop WMNs. They are intra-flow and inter-flow interferences.

Intra-flow interference occurs due to the adjacent nodes on the same routing path. They compete against each other for channel bandwidth. This intra-flow interference causes throughput to degrade severely due to the consumption of the flow bandwidth across each node on the same routing path. The hop count of the flow increases

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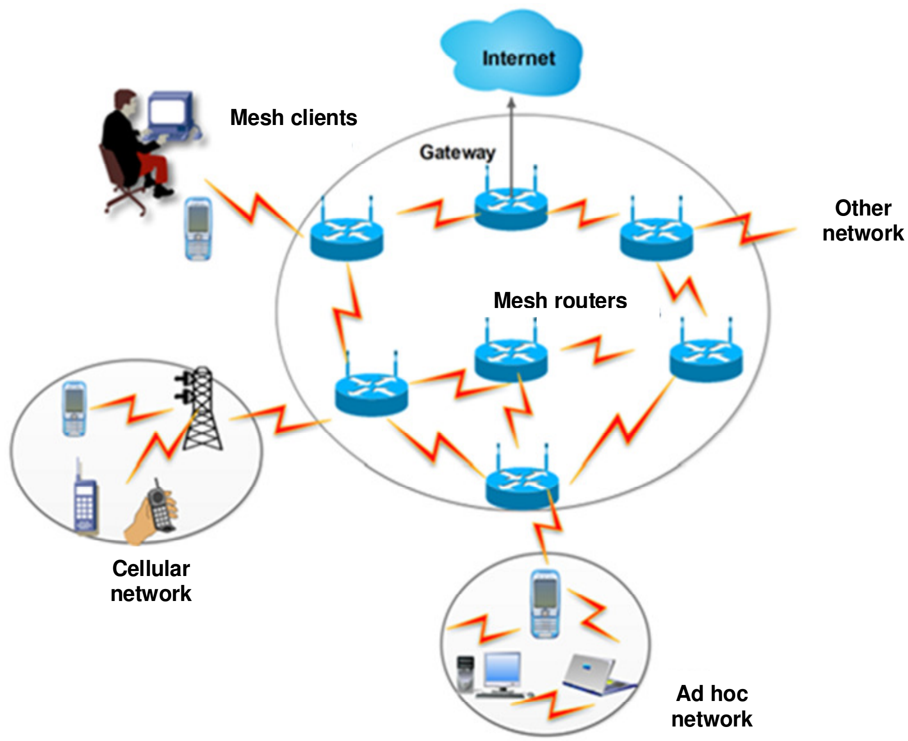

Figure 1. Wireless mesh architecture (Siraj and Bakar, 2011).

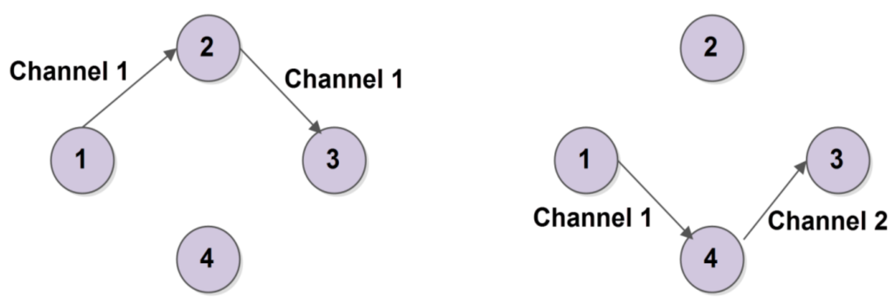

Figure 2. Intra-flow interference.

with an increase in end to end delay. This causes congestion. For example in Figure 2, it is shown that the path 1→2→3 causes intra-flow interference because of the reuse of channel 1 on the flow 1→2 and from 2→3. So the path 1→4 →3 does not have intra-flow interference due to the assigning of two different channels between 1→4 and 4→3. We can say that 1→4→3 is a better path in comparison to 1→2→3. So a good intra-flow aware interference metric should assign 1→4→3 a lower weight than 1→2→3. In other words, we can say that a good routing metric reduces inter-flow interference by selecting non-overlapping channels for adjacent hops of a path. Inter-flow interference is the interference occurring due to the other flows operating on the same channels and competing for the medium. This is caused by the multiple flows between different routing paths as shown in Figure 3. This not only consumes bandwidth of the nodes along its route, it also competes for bandwidth with the nodes following in the neighborhood. In comparison to intra-flow interference, inter-flow interference is harder to control due to the involvement of multiple flows and routes. Figure 3 shows inter-flow interference due to the two paths namely 1→4→3 and 5→6→7. A good inter-flow aware metric should assign a low weight 1→2→3 then to 1→4→3 as path 1→2→3 has ess inter-flow interference. Besides, the above two critical factors discussed, load

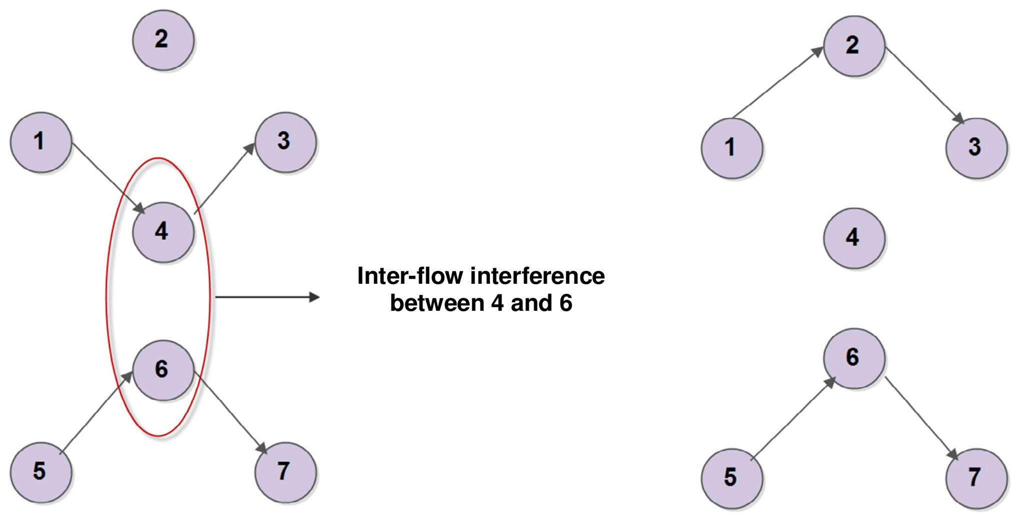

Figure 3. Inter-flow interference.

balancing is an important factor. An unbalanced load can cause traffic overload at the channels or at the center of the network or at the gateway. Channel overloading is a problem in multi-radio mesh network whereby some channels become overloaded in comparison to other channels. Center overloading results due to the presence of nodes at the center and they constitute a shortest path, in comparison to the other nodes in the network. Gateway overloading occurs due to the concentration of nodes at the gateway. As a result of this there is a load imbalance at various gateways. So a good metric ability is to balance load thereby providing a fair usage of the network.

In this paper, we propose a load balancing interference aware routing metric (LBIARM) for multi hop multi-channel WMN which captures the interaction between the same flow (intra-flow interference) and across different flows (inter-flow interference) and traffic load in multi hop and multi-channel mesh networks.

RELATED WORK

Hop count is the traditional metric used in most MANET (http://www.ietf.org/html.charters/manet-charter.html). It is popular in ad hoc networks as it is easy to compute path with minimum number of hops however. It is the most common metric used in dynamic source routing (DSR) (Johnson and Maltz, 1996) and ad hoc on-demand distance vector (AODV) (Perkins et al., 2003) routing protocols.

It can often result in paths which have high loss ratio and poor throughput as slower links take more time to send packets. We see that hop count metric is not suitable for WMN due to parameters like congestion control, scalability and in establishment of paths with maximum throughput (De Couto et al., 2005). The hop count metric is not able to differentiate between either good quality wireless links or low quality wireless links. It just treats all links alike. This metric is just concerned with shorter path links which results in low throughput. It has the isotonicity property that is, efficiently finding minimum weight paths.

The expected transmission count (ETX) metric was proposed by De Couto et al. (2005) to address the above mentioned problem. The ETX is defined as the number of transmissions required to successfully deliver a packet over a wireless link at the media access control (MAC) layer. The ETX of a path is defined as sum of ETX of each link over the path. In mathematical terms, we can write:

$$P = 1-(1-P_f)\,(1-P_r) \qquad (1)$$

Where P, Probability of unsuccessful transmission of packet from node a to node b in a link; P_f, probability of path loss in forward direction; Pr, probability of path loss in reverse direction.

The expected number of transmissions to successfully deliver a packet in 1 hop can be expressed as:

$$ETX = \sum_{k=1}^{\infty} kp^k (1-p)^{k-1} = \frac{1}{1-p} \qquad (2)$$

The ETX metric for a single link is measured in terms of forward and reverse delivery ratio.

$$ETX = \frac{1}{D_f * D_r}$$

Where D_f, Forward delivery ratio is $(1-P_f)$; D_r, reverse delivery ratio is $(1-P_r)$.

The ETX is isotonic and suitable for single channel multi hop network but does not perform well for multi-channel multi hop network. It favors path having higher throughput over less number of hops. ETX does not take account of load and intra-flow interference. It is insensitive to various link rates. Due to this, it results in poor medium fairness in the network (Awerbuch et al., 2003). However, ETX does deal with inter-interference but indirectly. As ETX measures link layer losses, the links with high level of interference will have a higher packet loss rate and therefore a higher ETX value.

The expected transmission time (ETT) (Draves et al., 2004) was an improvement over ETX as it took into account the bandwidth of different links. ETT is defined as the time taken to successfully transmit a packet to the MAC layer.

$$ETT = ETX * \frac{S}{B} \qquad (3)$$

Where S, Average size of a packet; B, the current link bandwidth. ETT path metric was obtained by adding up all the ETT values of the individual links on the path.

The advantage of ETT metric was that it was isotonic and increased overall performance of the network by increasing the throughput of the path by measuring the link capacities. The disadvantage of this metric was that it did not consider the link load explicitly and as a result was not able to avoid routing traffic through already congested nodes and links. The second disadvantage was that it did not minimize intra-flow interference as it was not designed for multi radio networks.

The weighted cumulative expected transmission time (WCETT) (Draves et al., 2004) was designed to improve the ETT metric in the area of multi radio mesh networks by considering channel diversity. The WCETT metric of a path p is defined as follows:

$$WCETT_p = (1-\alpha) * \sum ETT + \alpha * MaxX_j \qquad (4)$$

Where X_j, Sum of ETT values of links that are on channel j in a system that has orthogonal channels.

$$X_j = \sum_{\text{hops on channel j}}^{n} ETT_i \quad 1 \leq j \leq k \qquad (5)$$

α is a tunable parameter between $0 \leq \alpha \leq 1$ which controls the preferences over path length versus channel diversity. WCETT is a weighted average of two components. The first term is usually the sum of the individual link ETTs while the second term which adds up the ETTs of all the links of a given channel adds channel diversity which results in low intra flow interference.

Using WCETT improves the performance of multi radio and multi rate wireless networks in comparison to ETX, ETT and hop count metrics. The problem with WCETT is that it is not isotonic and due to this it cannot be used with link state routing protocols where algorithms like Dijikstra (Dijkstra, 1959) or Bellman Ford (Bellman and Ford, 1958) are used. Secondly, WCETT does not consider explicitly the effect of interflow interference. Due to this sometimes routes are created which suffer from high levels of interference.

A number of routing metrics have been proposed for routing protocols in WMNs such as metric of interference and channel switching (MIC) (Yaling et al., 2005), load aware ETT (LAETT) (Harve et al., 2008), exclusive ETT (EETT) (Jiang et al., 2007), interference load aware (ILA) (Shila and Anjali, 2005), interference aware (IAWARE) (Subramanian et al., 2006), adaptive load aware routing metric (ALARM) (Pirzada et al., 2009) and a location aware routing metric (ALARM) (Eiman and Roy, 2008) were proposed to support load balanced routing and to consider intra and inter-flow interferences, in addition to being isotonic. We found that each routing metric has limitation in not meeting one or more criteria. In this work, we focus to propose a new routing metric called LBIARM which takes cares of all the above parameters.

LOAD BALANCING INTERFERENCE AWARE ROUTING METRIC (LBIARM)

Our new metric is an enhancement of WCETT. The first component is identical to WCETT. The second component considers channel diversity. The second part represents our effort to improve the performance of WCETT.

$$\text{LBIARM} = (1\text{-}\alpha)\sum_{i \in p} ETT_i + \alpha \sum_{i \in p} ETT_i * N_i \qquad (6)$$

Where N_i the set of interfering links on link I and $ETT = ETX * \frac{S}{B}$, where S, the average size of a packet; B, the current link bandwidth.

PERFORMANCE EVALUATION

In this section, performance of our proposed metric LBIARM is evaluated and compared with WCETT for a 4 X 4 grid mesh network shown in Figure 4. In the simulated WMN, 16 static mesh nodes are randomly deployed 800 x 800 m^2. The average distance between each pair of two one hop nodes is the same. The interference range is set to be approximately equal as all mesh routers are with similar transmission powers. The source nodes send constant bit rate (CBR) traffic with user datagram protocol

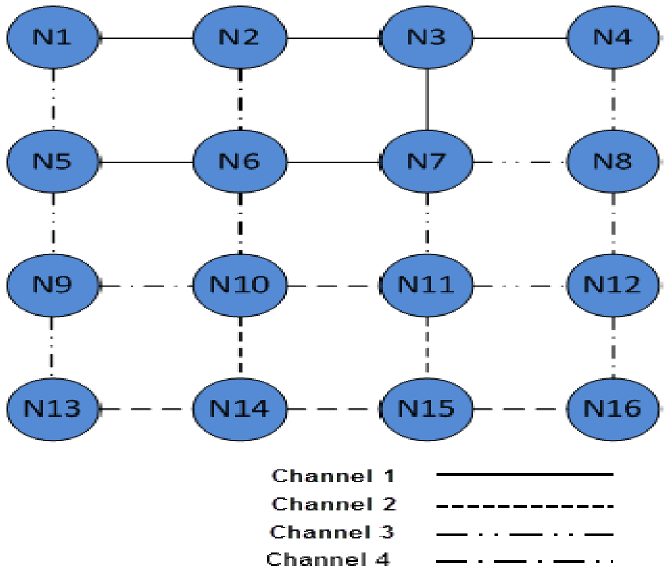

Figure 4. 4x4 Grid wireless mesh network with 4 channel assignment.

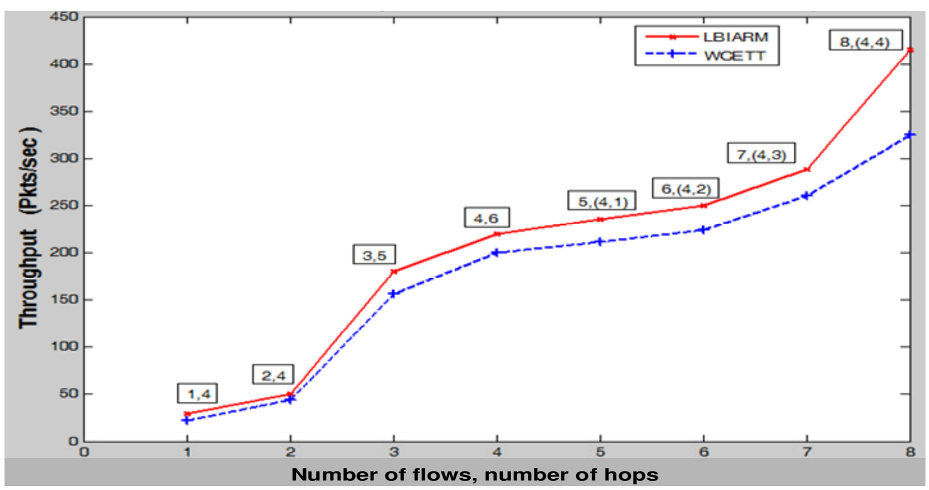

Figure 5. Performance comparison between WCETT and LBIARM.

(UDP) as the transport protocol. CBR consists of 1024 byte packets with a sending rate of 20 packets per second. OPNET Modeler 16.1 PL1 was used to build the simulation model. OPNET source code was modified to calculate ETT at each node. Interference traffic load was created by broadcasting HELLO messages at an interval of 1 second periodically to all neighbor nodes on channel i. Upon receiving this message, the neighbor nodes update the traffic load information of the corresponding nodes in their neighbor's table. Simultaneously, information of average packet buffered at the nodes is updated. For calculation of ETT, HELLO messages are also used. The value of α was taken as 0.3 for calculation of WCETT and LBIARM. This value was taken as it was found that optimum value of WCETT is when α=0.3. Based on Equations 4 and 6, different combinations of flows were used. Based on these values, the performance comparison between WCETT and LBIARM is done. In the first case, a single flow of 4 hops was taken. Then different combinations of flows were taken which are depicted in Figure 5. The following flow hops combination was taken. They were single flow of 4 hops, two flows of 4 hops, three flows of 5 hops, four flows of 6 hops, five flows (combination of four flows of 4 hops

Table 1. Simulation parameters.

Parameter	Value
Network scenario	Campus network
Network grid	800 X 800
Number of nodes	16
Number of radios	2
Number of channels	4
Packet size	1024
Interference range	400 m
Traffic model	Constant bit rate (CBR)
Transmission power	10 mW
Queue size at routers	50 Kbytes
Physical layer protocol	PHY 802.11 g
CBR sender's rate	20 packets/s
Transmission rate at physical layer	54 Mbits/s

and one flow of 5 hops), six flows (combination of four flows 4 hops and two flow of 5 hops), seven flows (combination of four flows of 4 hops and three flows of 5 hops) and eight flows (combination of four flows of 4 hops and four flows of 5 hops). Channel assignment was done randomly to test our metric performance. A typical channel assignment is shown in Figure 5. Table 1 shows the simulation parameters used.

From Figure 5, it is found that LBIARM throughput is better than WCETT. This shows that LBIARM takes into consideration the interfering co channel links resulting in a higher throughput.

CONCLUSION AND FUTURE WORK

In this work, we have proposed a new routing metric LBIARM for multi hop WMN. This metric takes into account intra-flow interference, inter-flow interference and traffic Load. From the simulation, we come to the conclusion that this metric performed better than WCETT. In our future work, this metric will be incorporated into a load balancing route discovery algorithm. This algorithm will be used to design a load balancing protocol which will choose a route that will deliver a high throughput, low end to end delay with minimized interference.

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