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A Unified Metric for Opportunistic Routing in Wireless Mesh Networks

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Abstract- **In wireless mesh networks, the routing of packets from source to destination is crucial and challenging task. The wireless mesh networks find applications in disaster management, video on demand, intelligent, health care systems, etc. Various routing protocols exist in literature to improve the efficiency of the wireless mesh networks calculated in terms of reliability, cost, throughput, error rate, etc. The opportunistic routing proves to be more efficient protocol best suited for wireless mesh networks as it avoids duplicate transmission and improves performance of the network. The routing metrics are essential to evaluate the best possible path for packet delivery. This paper conveys the essence of the existing metrics used for analyzing the routing protocol considered for evaluation. Further we introduce a new opportunistic routing metric called Unified Expected Distance Progress with Successful Transmission Rate (UEDPSTR) which is compared with the characteristics of the network.**

Index Terms* — *Metric, Opportunistic Routing, Wireless Mesh Network.

I. INTRODUCTION

The wireless mesh networks prove to be a promising robust network for consistent wireless services at a affordable cost. Wireless mesh networks are easily deployable with an economical maintenance cost. The wireless mesh network consists of mesh having different nodes interconnected to access internet, Wi-Fi by various devices such as printers, surveillance cameras, etc as shown in fig.1.

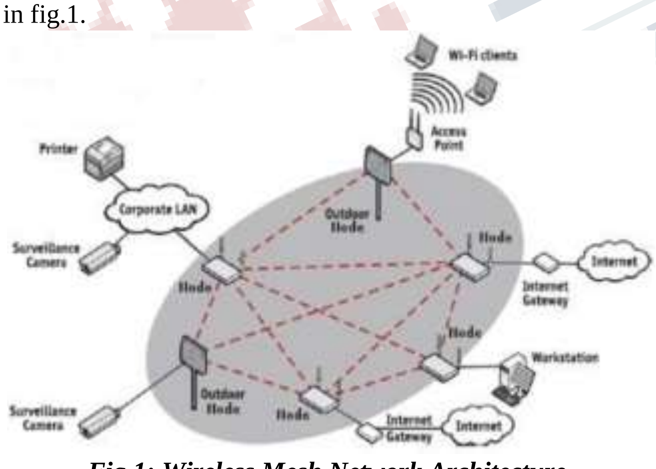

Fig.1: Wireless Mesh Network Architecture

The wireless mesh networks use packets to transfer information by using opportunistic routing protocols. These networks use the advantage of broadcast to all possible nodes. By using proper metrics, the protocols are devised to find the best routing path from source and destination.

The wireless mesh networks have advantages like less cost with scalable accommodation of additional nodes, reliable, self-configuring routers, decentralized i.e., static in nature, robust, flexible access from different locations, enhanced service, high data rates, etc.

As similar to any other network the mesh network too has disadvantages like higher power consumption, as every node is connected to other node due to which redundancy exists, vulnerable to attacks, hierarchical design limits the number of router adjacencies, difficulty to identify the problem if the network shuts down, etc. [7].

The wireless mesh networks find applications in many fields like distance education, residential broadband access, health care systems, video on demand, intelligent transport systems, disaster management, etc.

The opportunistic routing (OR) is a promising protocol for wireless networks as it is based on the broadcast nature which helps in avoiding duplicate transmissions and improves performance [3]. It has gained popularity for multihop wireless mesh networks due to its basic feature of diversity forwarding of packets routed or any path routing i.e., in a single transmission same packet is received by multiple nodes. Hence opportunistic routing balances load, so the robustness of the wireless network increases as multiple receiving nodes in the network act as potential relays until the packet reaches the destination. It works using the candidate selection and candidate coordination algorithms. There are certain parameters which determine the efficiency of the network. The routing metrics are used to predict the selection of the path for data transfer between source and destination. The definition of a good metric is an important criterion in designing a proper candidate selection and coordination algorithm.

The mesh routing protocol is said to be effective if it has the following features. The protocol must be distributive to have higher reliability. The routing algorithm has to be adaptable to topology changes. It has to avoid unnecessary wastage of bandwidth i.e., it must be loop-free. To prevent security vulnerabilities, security schemes are to be used. Its performance must be maintained even if the number of users increase i.e., it must be scalable. It has to ensure the required level of quality of service [4].

A routing metric is defined as a unit calculated by routing protocol to select or reject a routing path to connect source and destination to transfer data packets. There exist many metrics which affect the performance of Wireless mesh networks[5]. The routing metrics are used to evaluate the best possible route to transfer packets to the destined node. The routing metrics can have different optimization objectives such as performance, methods to collect the information, end-to-end route quality of individual link, etc[6].

This paper is organized as follows: section II describes the existing routing metrics. Section III describes the proposed routing metric. Section IV describes the comparison of all the metrics based on the characteristics of the network. Finally the paper is concluded.

II. EXISTING ROUTING METRICS

In literature many routing metrics are available; the following are the existing metrics.

(i). Hop Count considers the number of hops between source and destination. It is a distance routing metric.

(ii) Expected Distance Progress (EDP) from node s to the destination d using candidate set $C^{s,d} = \{c_1, c_2, ..., c_{ncand}\}$ (with c_1 being the highest priority, and c_{ncand} the least one) is defined as:

$$EDP(s,d,C^{s,d}) = \sum_{i=1}^{|C^{s,d}|} DP_{c_i}^{s,d} \times p_{s,c_i} \prod_{j=1}^{i-1} \left(1 - p_{s,c_j}\right)$$

The increase in the number of candidates would result in a larger EDP. It is a distance routing metric[1].

(iii) Per-hop Round Trip Time (RTT) measures the the round trip delay of unicast probes between neighbours. Queue delay exists due to the contention among nodes for low RTT link. RTT also generates high overhead and self interference. It is a Latency Routing Metric [2].

(iv) Load-count is a load balancing metric for wireless networks

$$Load - count = \sum_{i=1}^{n} Load_i$$

Where $Load_i$ is the traffic load on a node I captured by IFQ (Network Interface Queue) which is calculated as the number of remaining packets in the buffer. It is a traffic load routing metric [2].

(v) Expected Transmission Count Metric (ETX) is used to estimate the number of MAC layer transmissions and the packet loss rate and is given by

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

Where pf is the probability of successful forwarded packets and pr is the probability of successful received packets.

The probability of successful packet transmission from source a to destination b in a wireless link is

$$p = \left(1 - P_f\right) \times (1 - P_r)$$

This is an error rate routing metric.

(vi) Successful Transmission Rate (STR) captures the expected successful transmission rate between a node and the destination and is formulated as

$$STR(s,d,C^{s,d}) = \sum_{i=1}^{|C^{s,d}|} p_{s,c_i} \times STR(c_i,d,C^{c_i,d}) \prod_{j=1}^{i-1} \left(1 - p_{s,c_j}\right)$$

STR considers that there is a possibility that multiple neighbors may receive the packet, and a priority is assigned to each of them.

(vii) Expected Any-path Transmission (EAX) captures the ETX while taking into account the multiple paths that can be used in OR (Opportunistic Routing).

$$EAX(C^{s,d}, s, d) = S(C^{s,d}, s, d) + Z(C^{s,d}, s, d)$$

Where the ETX needed to deliver a packet from source s to atleast one of its candidates in $C^{s,d}$ is given by:

$$S(C^{s,d}, s, d) = \frac{1}{1 - \prod_{i=1}^{|C^{s,d}|}(1 - p_{s,c_i})}$$

And The ETX used to reach the destination d from one of the nodes in $C^{s,d}$, which is responsible for forwarding the packet, is

$$Z(C^{s,d}, s, d) = \frac{\sum_{i=1}^{|C^{s,d}|} EAX(C^{c_i,d}, c_i, d) P_{s,c_i} \prod_{j=1}^{i-1}\left(1 - P_{s,c_j}\right)}{1 - \prod_{i=1}^{|C^{s,d}|}(1 - p_{s,c_i})}$$

(vii) **Opportunistic Residual Expected Network Utilities (OpRENU) is** based on a function of benefit and transmission cost. After successfully delivering a transmitted packet, the utility of the delivery is defined as the benefit after deducing the cost of transmission which is formulated as:

$$Opu_s^{C^{s,d}} = \sum_{i=1}^{|C^{s,d}|}\left(Opu_i^{C^{i,d}} \times P_{s,i} \prod_{j=1}^{i-1}(1 - P_{s,j})\right) - COST$$

where $Opu_i^{Cs,d}$ is the OpRENU of node i employed for the purpose of reaching destination d by using Cs,d, and COST is the transmission cost at node s.

(viii) Expected Transmission Time (ETT) estimates the time a data packet needs to be successfully transmitted on a link. It is formulated as

ETT = ETX × S/B

where S is the packet size and B is the link capacity

Also the ETT metric considers the best throughput achievable (r_t) and the delivery probability of ACK packets in the reverse direction (p_{ACK}). Thus,

$$ETT = 1/(r_t \times p_{ACK}).$$

(ix) Weighted Cumulative ETT (WCETT) is also proposed by Draves et al [5] 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

$$WCETT(r) = (1 - p)ETT_i + p \max_{1 \le j \le k} X_j$$

Where p is a parameter, $0 \le p \le 1$. And path r uses X_j number of times of channel j.

Or alternatively is represented as

$$WCETT_p = (1 - \alpha) * \sum ETT + \alpha * Max\, X_j$$

Where α is a tunable parameter between 0≤α≤ 1 which controls the preferences over the path length versus channel diversity. And Xj = Summation of links ETT values which are on channel j in a system having orthogonal channels.

$$X_j = \sum_{hops\ on\ channel\ j}^{n} ETT_i \quad 1 \le j \le k$$

(x) Weighted Cumulative Expected Transmission Time with Load Balancing (WCETT-LB) is based on the WCETT routing metric, and is defined as

$$WCETT - LB(p) = WCETT(p) + L(p)$$

Where

$$L(p) = \sum_{node\ i\epsilon p} \frac{QL_i}{b_i} + min(ETT)N_i$$

This in addition to all the features of WCETT, considers the traffic concentration and congestion level at all the nodes in the path p. It has much lower end-to-end delay than hop count.

(xi) The loading aware routing metric is the weighted average of the Contention Windows that a frame has to undergo before being received successfully is represented as

$$\overline{CW} = \frac{1 - FER}{1 - FER^{r+1}} \frac{1 - (2 \cdot FER)^{r+1}}{1 - 2 \cdot FER} CW_0$$

Where FER is frame error rate, CW0 minimum Contention Window and r is the maximum back-off stage.

It takes into consideration the two factors i.e., the congestion level and the channel utilization. It is suitable for scalable network solution and is used in multi-gateway, multi-radio and multi-channel networks.

(xii) Metric of Interference and Channel Switching (MIC) considers inter and intra-flow interference effects besides providing load balancing. For a path p

$$\text{MIC}(p) = \frac{1}{N * \min(ETT)} \sum_{i\epsilon p} IRU_L + \sum_{i\epsilon p} CSC_i$$

N = Total nodes and min (ETT) = Network’s least ETT value

It consists of components of MIC, IRU (Interference Aware Resource Usage) and CSC (Channel Switching Cost).

$$\mathrm{IRU_L} = \mathrm{ETT_L} * \mathrm{N_L}$$

$$\mathrm{CSC_i} = \mathrm{w1 \; if \; Ch_{i-1}} = \mathrm{CH_i}$$

$$\mathrm{CSC_i} = \mathrm{w2 \; if \; Ch_{i-1}} \neq \mathrm{Ch_i},\; 0 \leq \mathrm{w1} < w2$$

NL is the group of neighbour nodes, which interferes with communications on link I. CH denotes channel allocated for it node communication and i-1 denotes the earlier hop of ith node on the path p [8].

(xiii) Load Aware Expected Transmission Time (LAETT) is a combination of load estimation and features of wireless access. It comprises of an implementation of ETT metric[11].

$$\mathrm{ETT_{jk}} = \mathrm{ETX_{jk}} * \frac{\mathrm{S}}{\mathrm{B_{jk}}}$$

where
$\mathrm{ETX_{jk}}$ = Expected transmission count on the link(j,k)

S = Size of the packet

$\mathrm{B_{jk}}$ = Bit rate

$\mathrm{B_{jk}} = \frac{\mathrm{B_j}}{\lambda_{\mathrm{jk}}}$ where Bj is the jth node communication rate

λ_{jk} = Link Quality Factor
λ_{jk} = 1 for a very good link

Remaining capacity (RCi) for every node is

$$RC_j = B_j - \sum_{k=1}^{N} g_{jl}\,\lambda_{jl}$$

fjl is the rate of transmission of current flow Nj that travels across jth node. The flow cost on the leftover bandwidth[10] is weighted by factor *jl*.

Then LAETT is formulated as

$$LAETT_{jk} = ETX_{jk} * \frac{S}{\frac{RC_j + RC_k}{2\lambda_{jk}}}$$

(***xiv) Exclusive Expected Transmission Time (EETT)*** is an innovative routing metric which is interference aware. It finds multichannel routes having minimum interference to have a high throughput[9]. Multi-channel paths are given better valuation by it. The kth link EETT is given by

$$EETT_k = \sum_{link_i \epsilon IS(k)} ETT_i$$

(xv) Interference Load Aware (ILA) consists of two components: Channel Switching Cost (CSC) and Metric of channel interference (MTI).

CSC component can be defined by

$$CSC_j = w1 \; if \; Ch_{j-1} = Ch_j$$
$$CSC_j = w2 \; if \; Ch_{j-1} \neq Ch_j,\; 0 \leq w1 < w2$$

Ch (j) represents channel assigned for node the transmission and j-1 represents the previous hop of the node j along path p.

MTI metric can be defined by

$$MTI_j(Q) = ETT_{jk}(Q) * AIL_{jk}(Q), N_l(Q) \neq 0$$
$$MTI_j(Q) = ETT_{ij}(Q), N_l(Q) = 0$$

Where

AIL_{jk} = Neighbors average load which may interfere when communicating amongst nodes j and k using channel Q.

$$AIL_{jk}(Q) = \sum_{NL} \frac{IL_{jk}(Q)}{N_L(Q)}, N_L(Q) = N_j(Q) \cup N_k(Q)$$

$Il_{jk}(Q)$ = Neighbors interfering load

$N_L(Q)$ = Interfering nodes set of neighbors j and k

Scaling factor α is applied to MTI metric for balancing the difference in magnitude of two components (MTI and CSC)[9]. A can be represented as:

$$\frac{1}{\alpha} = \min(ETT) * \min(AIL), N_l(Q) \neq 0$$

$$\frac{1}{\alpha} = \min(ETT), N_l(Q) = 0$$

min(AIL) = load average and
min(ETT) = least ETT

(xvi) Interference Aware Routing Metric (iAWARE) considers both inter-flow and intra-flow interference in wireless mesh networks.

$$iAware(p) = (1-\alpha) * \sum_{i=1}^{n} iAware_i + \alpha * \max_{1 \leq k \leq l} X_k$$

Xk is identical to WCETT. For a link k,the iAWARE value is

$iAware_k = \frac{ETT_k}{IR_k}$

Ir =Interference ratio among two nodes a and b for a link k.

$IR_k = \min(IR_k(a), IR_k(b))$

$$IR_j(a) = \frac{SINR_l(a)}{SNR_l(a)}$$

SNRl (a) = for link l node a's signal to noise ratio

III. PROPOSED METRIC

The proposed routing metric is a combination of successful Transmission Rate and Expected Distance Progress. As the probability of a packet reaching the destination is dependent on the path chosen from the multiple neighbors which received the packet, the expected distance progress can be slightly modified by introducing the metric relating the expected successful transmission rate between source and destination node. The unified expected distance progress with successful transmission rate (UEDPSTR) is given by

$$\mathbf{UEDPSTR(s,d,Cs,d)} = \sum_{i=1}^{|C^{s,d}|} \mathbf{DP}_{C_i}^{s,d} \times \mathbf{STR}(\mathbf{s},\mathbf{d},\mathbf{C^{s,d}})$$

Where,

$STR(s,d,C^{s,d}) = \sum_{i=1}^{|C^{s,d}|} p_{s,c_i} \times STR(c_i,d,C^{c_i,d}) \prod_{j=1}^{i-1} \big(1 - ps,cj$

This metric is useful in estimating the successful transmission rate based on distance routing metric and also can be used to minimize delay based on the locally available information and maximize the probability of data delivery using the active probing technique.

IV. COMPARISON OF METRICS

The routing metrics designed can be classified as

1. Topology based metric such as Hop Count.
2. Active probing based metrics such as Expected Transmission Count Expected Transmission Time, etc.
3. Energy aware metrics such as iAWARE, etc.

Further the routing metrics can be classified under mobility aware metrics and signal strength based metrics.
Since every metric cannot satisfy all the characteristics required for the routing different metrics are necessary. The basic comparison of the metrics is shown in table.1.

Table.1: Comparison of Routing Metrics

S. No	Routing Metric	Optimization Objectives	Metric Computation Method
1	Hop Count	Minimize Delay	Use of Locally Available Information
2	Expected Distance Progress (EDP)	Minimize Delay	Use of Locally Available Information
3	Per-hop Round Trip Time (RTT)	Minimize Delay	Active Probing
4	Load Count	Load Balancing	Active Probing
5	Expected Transmission Count Metric (ETX)	Maximize Probability of Data delivery	Active Probing
6	Successful transmission Rate (STR)	Maximize Probability of Data delivery	Active Probing
7	Expected Any-path Transmission (EAX)	Maximize Probability of Data delivery	Active Probing
8	Opportunistic Residual Expected Network Utilities (OpRENU)	Deducing cost of transmission	Active Probing
9	Expected Transmission Time (ETT)	Maximize Probability of Data delivery	Active Probing
10	Weighted Cumulative ETT (WCETT)	Maximize Probability of Data delivery	Active Probing
11	Weighted Cumulative Expected Transmission Time with Load Balancing (WCETT-LB)	Maximize Probability of Data delivery	Active Probing
12	Weighted Average of the Contention Windows	Maximize Probability of Data delivery	Active Probing
13	Metric of Interference and Channel Switching (MIC)	Equally distribute traffic load	Use of Locally Available Information
14	Load Aware	Minimize	Active Probing

	Expected Transmission Time (LAETT)	Delay and Maximize Probability of Data delivery	
15	Exclusive Expected Transmission Time (EETT)	Minimize Delay and Maximize Probability of Data delivery	Active Probing
16	Interference load Aware (ILA)	Equally distribute traffic load	Use of Locally Available Information
17	Interference Aware Routing Metric (iAWARE)	Equally distribute traffic load	Use of Locally Available Information
18	Unified Expected Distance Progress with Successful Transmission Rate (UEDPSTR)	Minimize Delay and Maximize Probability of Data delivery	Use of Locally Available Information and active probing

V. CONCLUSION

This paper summarizes the existing routing metrics devised for wireless mesh networks by various authors. A unified routing metric is proposed that describes the completeness of the metric with expected distance progress and successful transmission rate. The unified expected distance progress with successful transmission rate can be used to minimize delay based on the locally available information and maximize the probability of data delivery using the active probing technique which is derived based on summation function.

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