GU J Sci 30(2): 45-59 (2017)

Gazi University

Journal of Science

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Energy Efficient Routing Metric in Wireless Mesh Network

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Article Info

Received: 01/12/2016
Accepted: 14/04/2017

Keywords

Energy efficient communication
Wireless mesh network
Queue
Overhearing
Airtime link metric
HWMP

Abstract

Wireless Mesh Network (WMN) can provide high bandwidth Internet access to end users. Energy conservation is a key parameter for green and cost effective communication. As energy efficiency has not been given due consideration in WMN by researchers. With increasing interest in WMN, this research presents an energy efficient routing metric by considering energy due to transmission, reception, retransmission, overhearing and queue stability. Results in terms of throughput and energy consumption have been compared with that of standardization arena i.e. airtime link metric.

1. INTRODUCTION

With increasing usage of mobile digital gadgets, wireless Internet access is a vital part of today life. Wireless Mesh Network (WMN) offers high bandwidth Internet access to users via gateway nodes. Mesh routers (MRs) at backhaul in WMN can carry traffic from users to gateway or vice versa in multi hop fashion. WMN eliminate need of line of sight communication and can be characterized as cost effective, easy to maintain and fast to setup. WMN architecture is suitable for deployment in adverse or dynamic environment, which leads to rapid growth in the market for wireless mesh networking.

MRs in WMN are fixed and may not be resource constrained. So, the existing studies in WMNs have not paid much attention in energy-efficient perspective. Further energy consumption has complex relationship over multiple factors. Previous energy models ignore consumption due to overhearing, retransmission of packets and queue overflow. So, the real energy expenditure is far away from computed. As the current research in WMNs has not paid much attention in establishing that the routing metric developed for WMN is energy efficient. It is vital to analysis energy cost for transmitting a packet from source to designation over single or multiple hops.

Energy conservation approaches in WMN are in contrast to that for energy constrained network. In network with battery operated nodes, energy aware routing minimizes the energy consumption by considering battery lifetime. For prolong operation of network, objective of energy efficiency shift towards fare use of available battery among all network nodes. While in WMN the objective is overall energy minimization.

The main contributions of the paper includes: firstly, traditional routing metrics for WMN has been studied. Secondly, a new energy aware routing metric has been proposed. The routing metric will choose path with minimum energy consumption. Thirdly, the performance of the proposed metrics has been analyzed with that of standardization arena i.e. airtime link metric.

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2. ROUTING METRICS IN WIRELESS

Different requirements of routing protocol are realized with the properties of a routing metric. So designing routing metric is an essential component. Routing metric helps a routing algorithm to evaluate a path to choose best route from source to destination. Number of routing metrics exists in literature few most popular energy efficient routing metrics in WMN are described below.

Hop count (HC) [1]:- This is simplest metric. Various routing algorithms like AODV, DSR, DSDV, OLSR etc implements hop count metric. But HC doesn't consider energy conservation and treat all links identical. Moreover it provides effect of path length on flow performance. Load, capacity, channel range, packet loss rate, and interference experienced by the links have not been considered.

Expected transmission count (ETX) [2,3]:- The metric is an evaluation of expected transmission count required for a packet to be delivered without error. Packet loss rate is collected from the MAC layer. It is a measure of quality of path for a future event as opposed to past event.

$$ETX = \sum_{k=0}^{\infty} ke^{k-1}(1-e) = \frac{1}{1-e} \quad (1)$$

Considering error on forward and backward path (1) becomes as follows:

$$ETX = \frac{1}{(1-e_f)(1-e_b)} \quad (2)$$

Where, e_f, e_b are forward and backward error probabilities respectively.

Long and error prone paths have higher value for ETX, hence ETX capture both quality and length of path. But metric doesn't consider available link bandwidth and lacks direct energy conservation.Expected Transmission Time (ETT)[4]:- It is an extension to ETX to consider impact of link bandwidth. Various routing algorithms like RBAR, OAR etc uses ETT. It defined as the expected MAC layer duration required for successful transmission of a packet on a link.

$$ETT = ETX \times \frac{S}{R} \quad (3)$$

Where, S denotes size of packet, R refers to link rate. ETT also has no direct energy conservation. So, may choose path with nodes having low remaining battery.

Weighted Cumulative Expected transmission Time (WCETT)[5]:- It is an enhancement over ETT to account interference on links using common channel i.e. interflow interference. First term in (4) favors shorter and high quality links. While second term support path which are more diverse in channel by taking sum of its all link on common channel and then takes maximum over all channels. WCETT for k is number of channel is given in (4).

$$(1-\beta)\sum_{l \in p} ETT_l + \beta \max_{1 \le i \le k} y_i \quad (4)$$

Where, $y_{i} = \sum_{\text{link } l \text{ on channel } j}(ETT_l) \quad 1 \le j \le k$

A further extensions to WCETT is given by Metric of Interface and Channel switching, which considers intra-flow interference and hence channel diversity. WCETT is useful in multi-radio, multi-rate network.
Power Aware Metrics (PAM) [6]:- The Metric is an extension for airtime link metric of Hybrid Wireless Mesh Protocol (HWMP) to consider the battery life time of node as below.

$$M = ALM + kM_E \quad (5)$$

Where,

$$M_E = \frac{L_{max} + L^2}{L \times T}, \; L_{max} = \frac{C}{I_{min}}$$

k is a weight factor, ALM is HWMP airtime link metric given by (14) and C is capacity of a battery.. $I_{min}$is minimum current, L is life time of a node and T is normalization factor.Expected Transmission Energy (ETE)[7]:- Routing Metrics make certain that no node withdraw energy at a rate considerably above than other nodes, while concurrently keeping the average energy expenditure rate low.

Minimal Total Power (MTP)[8]:- The metrics aimed at minimizing the overall energy consumption of network. Let $P = \{p_i\}$ is set of all possible paths from given source and destination. Energy consumption p_e^ialong a path p_i having x nodes $n_1, n_2, \ldots n_x$ is given by:

$$e(p_i) = \sum_{k=1 \ldots x-1} e_{n_k, n_{k+1}} \tag{6}$$

Where, $e_{n_k, n_{k+1}}$is energy consumption for transmission from node n_k to n_{k+1}. Value is higher on error prone links. Path p_m with minimum energy consumption is given below.

$$MTP = \min(e(p_i)) \text{ where } p_i \in P \tag{7}$$

Under ideal condition i.e. error and congestion free path, metric gives results same as of minimum hop count metric. MTP doesn't consider remaining battery level and hence network lifetime. Energy consumption along reversal path and ideal energy consumption has not been considered.Minimum battery cost (MBC)[9]:- The metric considers remaining battery of nodes along a path. A node is assigned cost value c_{n_i}based on remaining battery level.

$$c_{n_i} = \frac{\text{Remaining battery capacity}}{\text{Full battery capacity}} \tag{8}$$

Let $P = \{p_i\}$ is set of all possible paths from given source and destination. Energy consumption $e(p_i)$ along a path p_i having x nodes $n_1, n_2, \ldots n_x$ and hence MBC is given by (10).

$$e(p_i) = \sum_{k=1 \ldots x} C_{n_i} \tag{9}$$

$$MBC = \min(e(p_i)) \text{ where } p_i \in P \tag{10}$$

MBC doesn't consider overall energy consumption of network. It may select a route with nodes having small battery capacity. So, metric fails to characterize a node individually. Min-Max Battery Cost (MMBC)[10]:- Disadvantage of considering a route with nodes having small battery capacity in MBC has been addressed in MMBC. But again overall energy consumption of network has been ignored. Given $P = \{p_i\}$ as set of all possible paths from given source and destination, then metric can be represented by (11) given below.

$$MMBC = \min_{p_i \in p} \max_{n_i \in p_i} (e(p_i)) \tag{11}$$

Conditional max-min battery capacity (CMMBC) [11]:- The metric is a combination from MTP and MMBC. CMMBC firstly chooses path using MTP with nodes having remaining capacity c_{n_i} is above a minimum threshold levelμ. If no such path found then MMBC is used. Let $P = \{p_i\}$ is set of all possible paths from given source and destination node. Energy consumption $e(p_i)$ along a path p_i having x nodes $n_1, n_2, \ldots n_x$ is given by:

$$e(p_i) = \sum_{k=1 \ldots x-1} e_{n_k, n_{k+1}} \tag{12}$$

Where $e_{n_k, n_{k+1}}$is energy consumption for transmission from node n_k to n_{k+1}. Value is higher on interference (intra, inter or external) suspected and congested links.Then path p_m with minimum energy consumption is given by:

$$\mathrm{MTP} = \min(\mathrm{e}(\mathrm{p_i})) \tag{13}$$

Where $p_i \in P$ and $\forall n_i \in p_i\ c_{n_i} > \mu$.

3. ROUTING IN STANDARIZATION AREA

IEEE 802.11s uses Hybrid Wireless Mesh Protocol (HWMP) as default routing protocol. Radio Aware Optimized Link State Routing (RA-OLSR) an adaptation of OLSR for layer 2 is another optional protocol. HWMP can operate in both reactive mode and proactive. The reactive mode is given by Ad hoc On-Demand Distance Vector (AODV), adapted for MAC address based path selection. It offers flexibility in uncertain environment. While, aspects of proactive mode are inherited from distance vector routing protocol, which is more suitable in fixed topology and stable environment. Proactive mode is used when most of the traffic goes outside the gateway nodes. Proactive tree structure service is added to the on-demand mode. Both modes can be used concurrently. Major HWMP major elements are the path request (PREQ), path reply (PREP), path error (PERR), and root announcement (RANN). Link metric value resolves path from source to destination node. The metric information between mesh nodes is propagated in the PREQ, PREP, and RANN elements. The default path selection metric is airtime link metric (ALM) to calculate resources consumed by a packet to a link. It gives amount of resources required by a packet over a link. ALM can be calculated as below:

$$\mathrm{ALM} = \left(\mathrm{C} + \frac{\mathrm{T_s}}{\mathrm{R}}\right) \times \frac{1}{1-\mathrm{e}} \tag{14}$$

Where, T_s is size of trail packet with default value of 8192 bits in IEEE 802.11s. C is a constant factor depends on physical layer and represents cost of accessing the channel. R is data rate; e gives probability of packet with size T_s being corrupted due to transmission.

HWMP evaluate quality of links but does not consider energy efficiency as priority and may not be advantageous in many situations. Under same error rate over links, ALM tends to discover the minimum hop distance or may use that particular path for every communication. Further authors in [12-13] have considered delay due to queue length at intermediate nodes. But energy conservation has been ignored. Hence goal of this paper is to present energy aware path selection metric based on transmission, reception, retransmission, overhearing and queue stability.

4. SYSTEM MODEL

This section, presents the system model considered in this study. Let WMN is represented by undirected graph $G(A, M, G)$ with edge set $E = \{e_{i,j}\}$. Here, $'A'$ is set of mesh access point (MAP), to collects traffic from client and forwards same towards gateways node. While $'M'$ and $'G'$ denotes the number of MR and gateway nodes respectively. So, total number of nodes N in WMN is given by (15)

$$\mathrm{N} = \mathrm{A} + \mathrm{M} + \mathrm{G} \tag{15}$$

Role of MR nodes is to provide connectivity in partially disconnected area of network and enhance network performance in terms of throughput, energy efficiency, delay, fault tolerant etc. The packet generation process at each MAP is independent and identically distributed with mean passion arrival rateα_o.

a. Communication Energy Model

Energy consumption for transmitting, receiving or discarding a packet can be represented in linear form as below.

$$\mathrm{Energy} = \mathrm{mp_{size}} + \mathrm{b} \tag{16}$$

Where, b is fixed component due to channel acquisition overhead and device switch state. p_{size} denotes size of packet and m is an incremental part relative to size of packet.

b. Overhearing Packet Model

Overhearing from neighbor nodes leads to packets discard, leading to more energy expenditure. Overhearing is affected by node density. Broadcast traffic is received by all neighbor nodes within transmission range. Whereas, point-to point traffic in non-promiscuous mode is discarded by non destination nodes. Discarding a packet usually involve much less energy than receiving it in non-promiscuous. But in promiscuous mode energy cost of discarding a packet is almost equal to cost of receiving a packet. Also if discarding energy cost is high even than advantage of point-to point traffic over broadcasting is collision avoidance and data acknowledgement. Cost of discarding a packet at a node is proportional to number of packets p_j transmitted by j^{th} neighbor node. If cost of discarding a packet isE_p, then, total discarding cost $E_d$at node 'i' having n neighbors is given by sum of all outflows of neighbor nodes as given below.

$$E_d = \sum_{j=1..n} p_j E_p \qquad (17)$$

Table I gives typical value of parameters of IEEE 802.11 based node operating in 11 Mbps [14]. Energy consumption for a 512 bytes packet transmitted from source X to destination Y via intermediate node $'n'$ is also provided. In Table I, n ∈X denotes that node n is neighbor of node X. while, n ∉X signifies that node n is not a neighbor of node X, similarly for node Y. Figure 1 gives typical discard scenario of a packet at node n while a packet is being transmitted from node X to node Y.

Table 1. *Energy Consumption in IEEE 802.11 node in 11Mbps*

Mode	m	b	Energy Consumption (µJ)
Transmission	0.48	431	676.76
Receiving	0.12	316	377.44
Discarding at node n (n∈X, n∈Y)	0.11	66	122.32
Discarding at node n (n∈X, n∉Y)	0.11	42	98.32
Discarding at node n (n∉X,n∈Y)	0	38	38
Discarding at node n (n∉X,n∉Y)	0	0	0
Ideal state	48 mW		

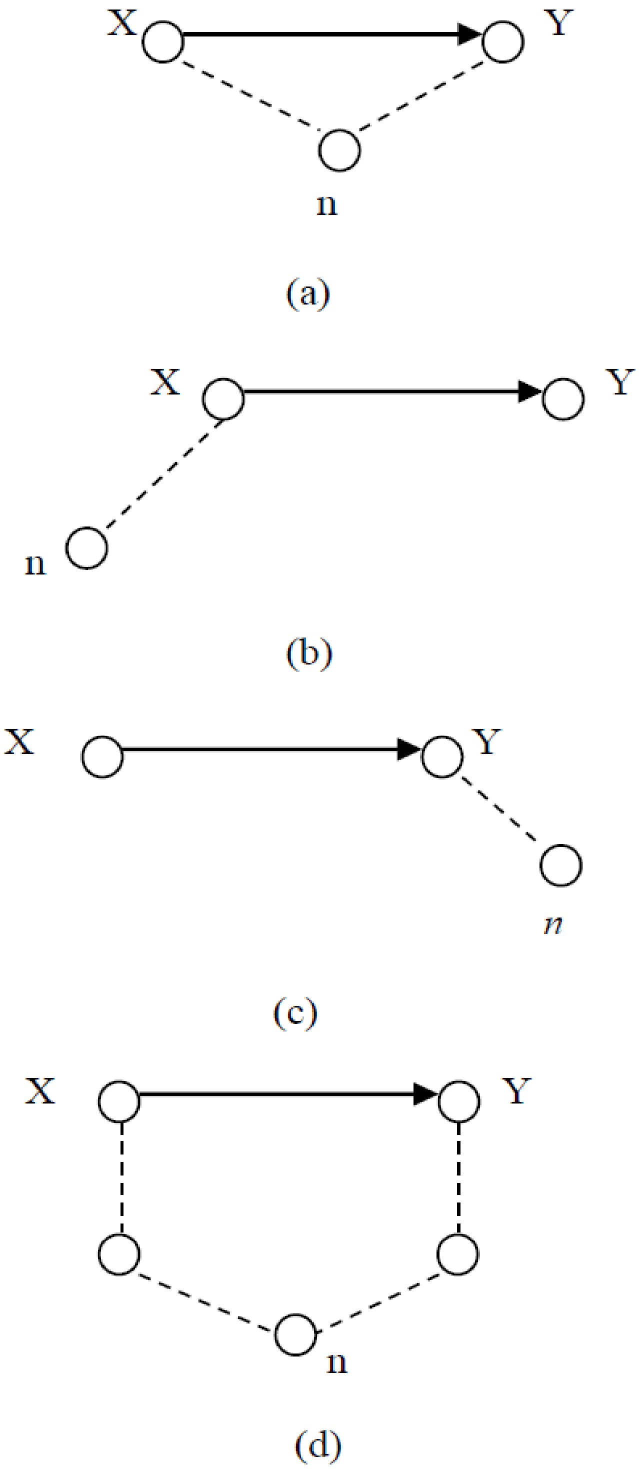


Fig.1. *(a) Discarding at node n (n∈X, n∈Y) (b) Discarding at node n (n∈X, n∉Y) (c) Discarding at node n(n∉X,n∈Y) (d) Discarding a node n (n∉X,n∉Y)*

c. Retransmission

Packet retransmission can be of two types :-(1) end to end retransmission (2) hop by hop retransmission. In first case, packet failure requires retransmission by original source node. While in second case, source node and all the middle nodes along the path offers retransmission in hop by hop manner. This research work assumes hop by hop retransmission.

d. Queuing Model

Mesh nodes in WMN have restricted buffering size. Nodes near to gateway nodes are added prone to buffer overflow. Vast buffer space, if viable, in mesh node can store large amount of data packet, and trim down buffer overflow; but, setting up large memory at each node is expensive and not practical. Buffer capacity at any node is essential as packets buffering in the source and intermediate nodes are required for some duration of time as due to error on link, few packets may not be received successfully and needs retransmission or packets need to wait till channel is available for transmission. At mesh node self-originated packets as well as the incoming packets from its neighbor nodes will be pushed in queue in sequential order. The first-come-first-served (FCFS) mechanism is assumed. At a network node buffer spill over will arise if the sum of the number of packets it originate and the number of packets it accept from neighbor nodes goes beyond its processing rate. FCFS at node $'i'$ having 3 neighbors is demonstrated in Fig. 2, packets are pushed to a common queue, and popped from queue head for deliver to outgoing link. Further, a queue management is essential to organize queue. Which can be broadly classified into two ways:- passive queue management and active queue management. First one is based on approach to drop packets when queue is full e.g. Droptail. While second one drops packets long before the buffer is actually full e.g. Random Early Detection (RED) to mitigate congestion in advance. This paper adopt passive queue management i.e. when the queue has no room left, the incoming packets at this instant are discarded immediately.

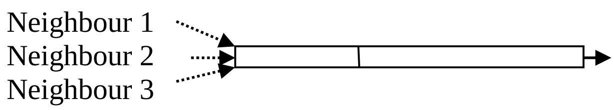


Fig 2. *Queue Management*

Denoting α_t as total packet arrival rate at node $'i'$, given by packets rate α_i received from i^{th}neighbor mesh nodes and its own generated packets α_o from its client nodes.

$$\alpha_t = \alpha_i^o + \sum_{i=1}^{n} \alpha_i \text{ , For a MR, } \alpha_i^o = 0 \tag{18}$$

If p_s is packet service probability at neighbor node $'i'$ due to given link quality and packet service time at the MAC layer then packet departure rate μ_i of a node having n neighbor nodes can be calculated by (19).

$$\mu_i = (1 - p_s)\alpha_t \tag{19}$$

e. Packet Service Time at the MAC Layer

IEEE 802.11s supports contention free channel access by reserving time period for packet transmission between mesh stations using MCF controlled channel access (MCCA).
Average per packet waiting time $S_P$is given by (20).

$$S_P = M_d + \lambda \tag{20}$$

Where, $M_d$is given a packet at the head of queue, time taken for its turn of time slot given by (21). λ denotes time taken to actually relay a packet on link. Let nodes can transmit one packet per time slotT_s. Packet arriving during current slot cannot be transmitted in current slot and has to wait for next available slot [15]. So, $\frac{T_s}{2}$ is average waiting time due to arrival during an active slot. Ignoring time taken in receiving back an acknowledgment frame.

$$M_d = \frac{T_s}{2} + W_S \tag{21}$$

$$\lambda = \frac{S}{R} \tag{22}$$

Where,

T_s= Duration of slot
W_S=Average waiting time for next available slot
S = Packet size
R = Transmissions rate of link

As due to error, there is probability that a packet needs transmission. For e_{l_i} as probability of corruption of packet on a linkl_i, factor $(1-e_{l_i})$represents the probability of packets retransmission. So net packet for transmission can be represented as $\alpha' = \frac{\alpha_t}{(1-e_{l_i})}$.
A queue is stable if net rate of packet arrival (α')< packet departure rate (μ).

$$\mu = \frac{1}{\left(\frac{T_S}{2}+W_S+\frac{S}{R}\right)} \tag{23}$$

5. IMPROVED ROUTING METRIC

The designed routing metric have following characteristics:

I. Path selection accounts transmission energy, receiving energy, link error rate, queue stability and discard energy.
II. Quality of service is maintained by bypassing traffic from congested nodes. Congested nodes are determined by considering queue stability based on processing and packet arrival rate.
III. Traffic with Poisson arrival rate has been assumed.

For a path p, given by order of nodes in sequence. If e_{l_i} is probability of corruption of packet on a linkl_l, then expected transmission attempts for successful transmission is given by $\frac{1}{1-e_{l_i}}$. When rate of processing is smaller to rate of packet arrival, then packets will be discarded after filling up queue to its maximum length Q_{max}. Such overflow path must be avoided altogether to avoid congestion. Figure 3 (a) and 3(b) represents case of a stable queue and unstable queue respectively. In fig 3(a) $\frac{\alpha}{\mu} = 1 \le 1$ and buffer is half full. In fig. 3 (b) $\frac{\alpha}{\mu} = 2 > 1$ and Q_{max} = 1 MB remaining part of queue will be filled after 0.5 sec and incoming packets will be rejected henceforth. Proposed energy aware routing metric can be described by (24) and further simplified by flowchart given in fig. 4.

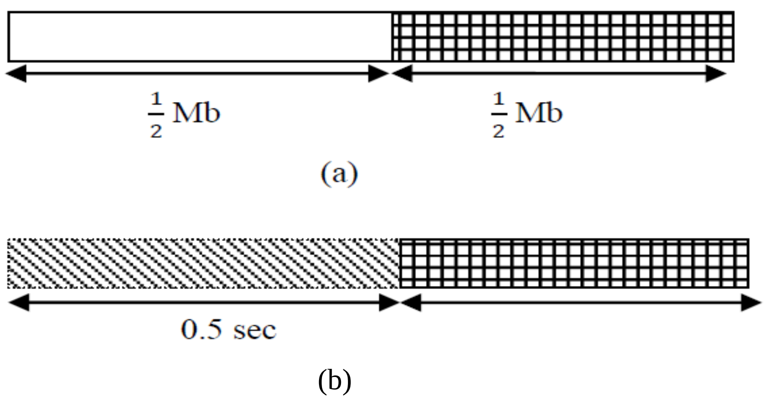


Fig 3. *(a) Stable queue,* $\frac{\alpha}{\mu} = 1$ *(b) Unstable queue* $\frac{\alpha}{\mu} = 2$

$$\text{EAPM} = \sum_{i\in p}\left(\frac{E_T^i+E_R^i}{1-e_{l_i}}\right)k_1 + \sum_{j\notin p}\left(\frac{E_D^j}{1-e_{l_i}}\right)k_1 + \sum_{i\in p} HQ^i_{congestion}\,k_2 \tag{24}$$

if $\frac{\alpha}{\mu} \le 1 \Rightarrow Q^i_{congestion} = 0 \Rightarrow$ Queue is stable, and there is no congestion.

else if $\frac{\alpha}{\mu} > 1 \Rightarrow Q^i_{congestion} = 1$ ⇒Queue is not stable and packets will be dropped after filling queue capacity.

Where, k_1, k_2 are weight factor such that $0 \le k_1, k_2 \le 1$

E^i_T = Transmission energy consumed at node i
E^i_R = Reception energy consumed at node i
E^j_D =Discard energy at neighbor node j, due to ongoing transmissions.
n = Number of peer nodes
e_{l_i} = Error rate on link l_i
S = Size of packet
μ = Processing rate given by (23)
α_i = Packet arrival rate after new flow
H = A high constant value

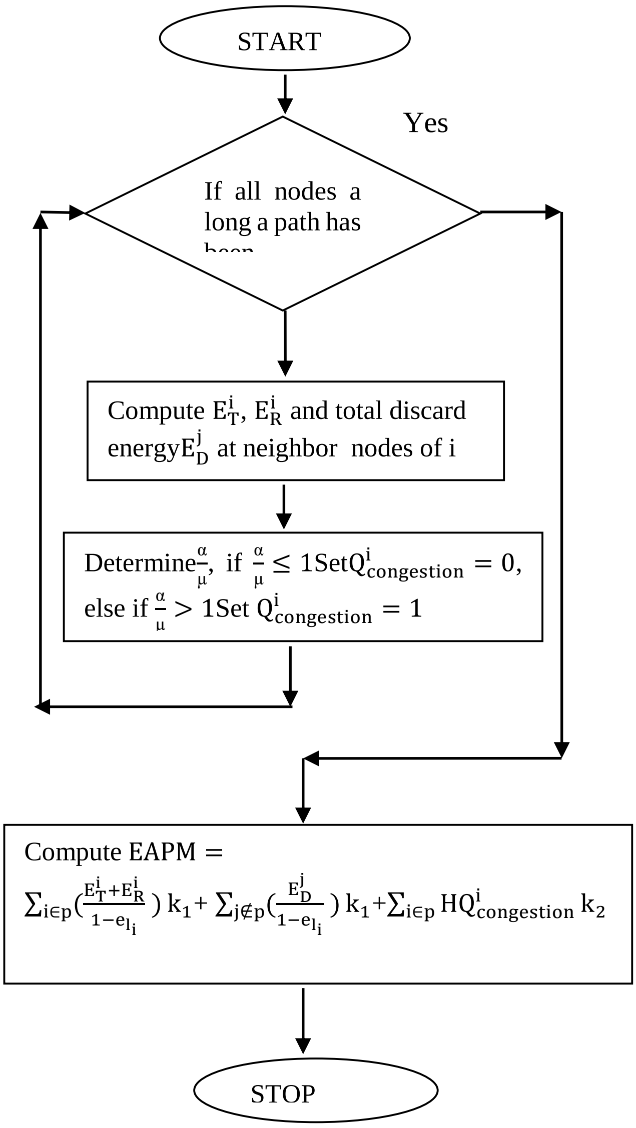


Fig. 4. *Flow Diagram for computing routing metric of a path*

In equation (24), first factor, gives energy consumption for actual transmission or reception or discarding of a packet. This also account expected number of required transmissions due to link quality. Second factor considers energy consumption due to queue stability. Buffer overflows leads to packet drop and signal for possible congestion on a path. So, metric avoids choosing congested paths and hence save energy consumption.

6. SIMULATION AND ANALYSIS

List of parameters used for analysis are listed in Table II.

Table 2. *List of Parameters*

Parameters		Value
C		185 μs
Size of trail packet T_s		185 μs
R		11Mbps
Packet size S		512 bytes
α_o		1 Mbps, 3 Mbps, 5 Mbps
k1	Unlimited Buffer	1
	Limited Buffer	1
k2	Unlimited Buffer	0
	Limited Buffer	1
H		1000
Retry Limit		3
Frame Duration		102.4 ms

a. Small Topology

Consider a WMN network with 6 nodes as in Fig. 5. Link$l_{3,2}$, $l_{2,1}$, $l_{4,1}l_{6,2}$, $l_{5,2}$ and $l_{3,4}$ have error rate of 0.2, 0.1, 0.1, 0.1, 0, 0, 0.2 respectively.

Case I. Unlimited Buffer Capacity:

Mesh nodes have no buffer constraint. Node '3' has to transmit packets with rate $\alpha_o = 5$ Mbps towards gateway 1. Airtime Metric choose path {3,2,1}, but due to discard energy optimal path for proposed metric is {3,4,1}. Observations along with energy saving with respect to airtime link metric are given in Table-III.

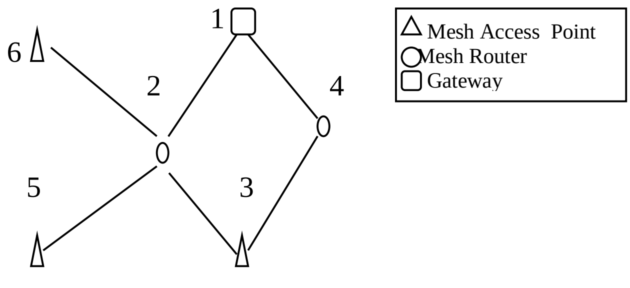


Fig. 5. Small Topology Wireless Mesh Network

Case II. Limited Buffer Capacity:

Except gateway node all other mesh nodes have limited buffer capacity. Traffic rate of 11 Mbps, 5 Mbps implies 275 packets/frame, 125 packets/frame respectively. Let CBR traffic of 5 Mbps is on going from node 6 to node 1 then α_6=5 Mbps. Now in order to support traffic at rate of 5 Mbps from node 3 to 1, i.e. α_3=5 Mbps. In scenario of wireless interference in single channel, maximum departure rate can be derived as $\mu_3 = 137$ packets/frame, $\mu_4 = 137$ packets/frame, $\mu_2 = 110$ packets/frame.

Let's compute metric value via possible two routes. Route (3,4,1) givesα_4=125 and $\alpha_2 = 125$ while for route (3,2,1) α_4=0, $\alpha_2 = 200$ are calculated. As route (3,2,1) will eventually start dropping packets due to overflow, so (3,4,1) is again optimal.

b. Medium Topology

In other case a medium network scenario of 20 uniformly placed nodes has been considered. Nodes have limited buffer capacity. Proposed Routing Metric has been implemented in Matlab.

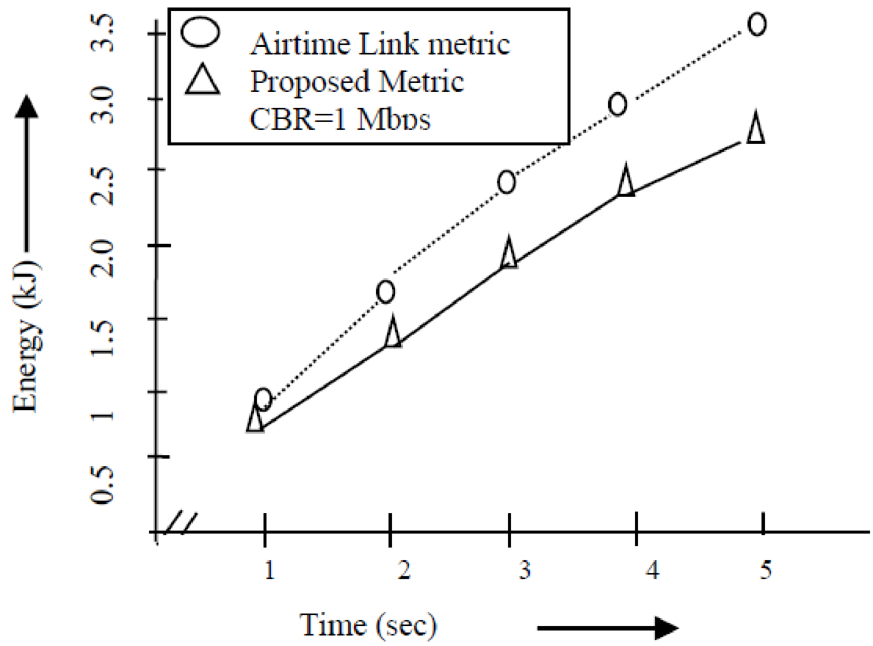
Table 3. *Observation Values*

Route → / Metric ↓	Energy Consumption at (3,2,1) (Joules)	Energy Consumption at (3,4,1) (Joules)	Selected Path	Relative Energy Efficiency (%)
Unlimited Buffer				
Airtime Metric	21*10-4	22*10-4	(3,2,1)	-
Proposed Metric	27.8 *10-4	27.21*10-4	(3,4,1)	.022
Limited Buffer				
Airtime Metric	21*10-4	22*10-4	(3,2,1)	-
Proposed Metric	$\frac{\alpha_2}{\mu_2} > 1$, 1000.01	$\frac{\alpha_2}{\mu_2} < 1$, 27.21*10-4	(3,4,1)	16.24

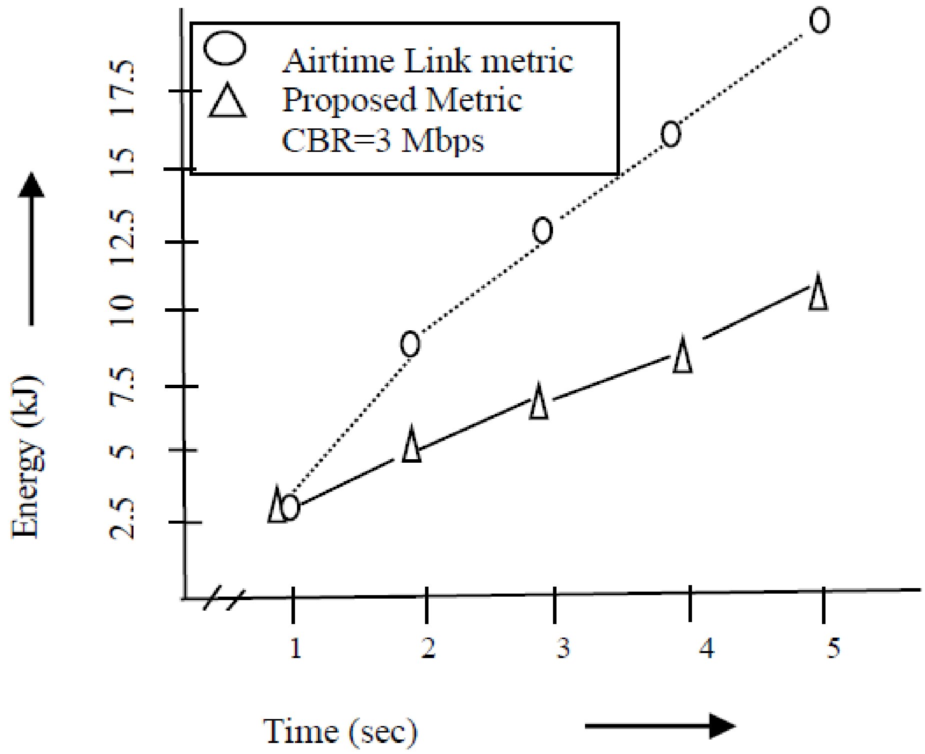
Results have been computed for two cases of MAPs having CBR=1 Mbps and 3 Mbps for run duration of 5 minutes. 5 MAPs have been selected randomly for each run. In all cases average results of 5 runs as shown in fig. 6 reveals that, proposed routing metric is more efficient in terms of energy and throughput.

Table 4. *CBR Traffic*

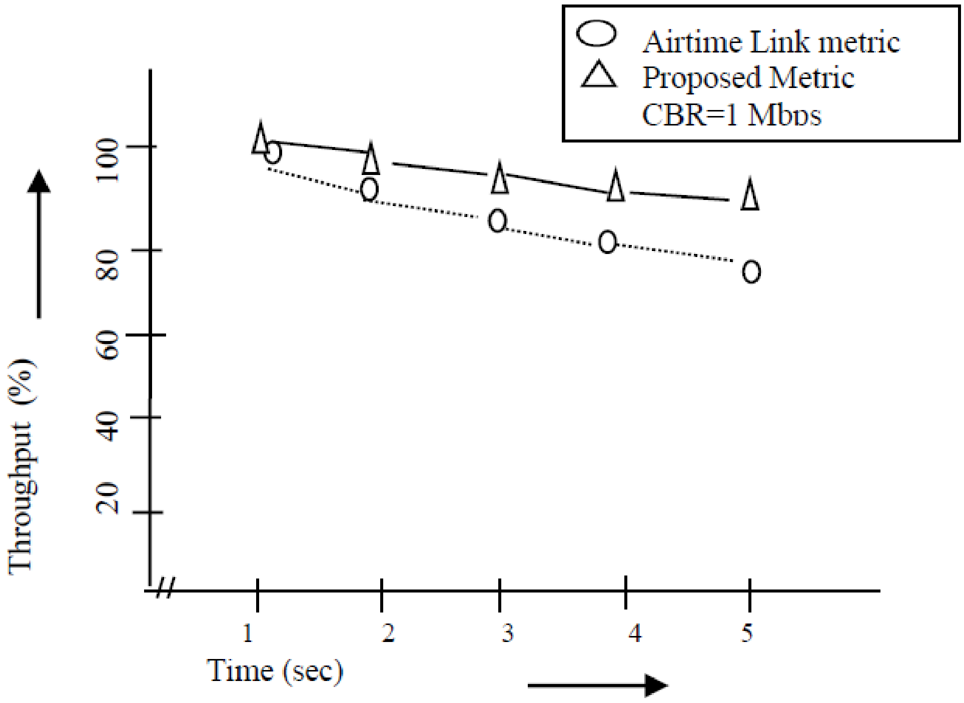
MAP No	Start Time	End time
1	0	5
2	1	5
3	2	5
4	3	5
5	4	5


Airtime Link metric
Proposed Metric
CBR=1 Mbps
Energy (kJ)
0.5
1
1.5
2.0
2.5
3.0
3.5
1
2
3
4
5
Time (sec)

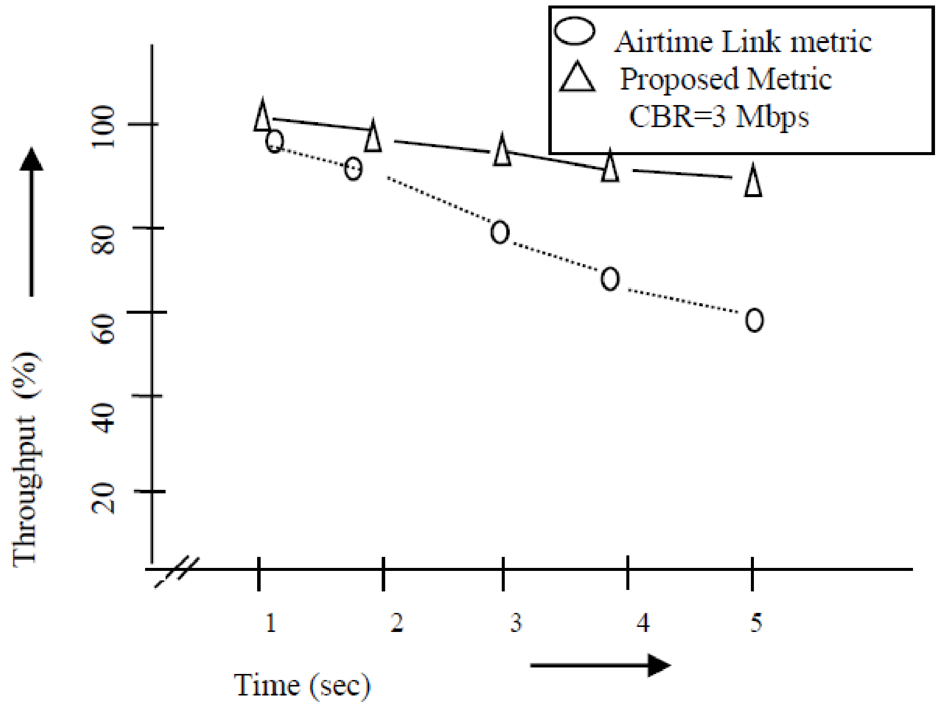
(a)


Airtime Link metric
Proposed Metric
CBR=3 Mbps
Energy (kJ)
2.5
5
7.5
10
12.5
15
17.5
1
2
3
4
5
Time (sec)

(b)



(c)



(d)

Fig. 6. *(a) Energy Analysis CBR=1 Mbps (b) Energy Analysis CBR=3Mbps (c) Throughput Analysis CBR=1 Mbps (d) Throughput Analysis CBR=3 Mbps.*

7. CONCLUSION

Energy aware traditional routing metrics in WMN are more inclined towards battery operated nodes. There are very few research focusing on network where nodes have sufficient power supply. Moreover routing metric in standardization area i.e. airtime link metric of IEEE 802.11s also does not consider energy as key parameter. Keeping this in view, this paper has proposed a routing metric by accounting energy consumption due to transmit, receive, discard, link quality and queue stability. Results have been compared with airtime link metric. It is observed that, proposed metric outperforms airtime link metric in terms of network throughput and energy efficiency.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

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