Link Expiration Time Aware Routing: Distributed Power Management in MANETs

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Abstract —In this paper, we propose a new power control algorithm for Mobile Ad hoc Network (MANET). The suggested algorithm is a Link Expiration Time Aware Distributed Power management algorithm, (LETPOW). Our main aim is to periodically check Connectivity, Transmission power, Interference level, Routing overhead and Node Mobility in MANET. We deliver a modified time-varying signal-to-interference-noise ratio (SINR) formula. The proposed algorithm considers additional parameters such as link expiration time, continuous time interval and the total number of scheduled slots compared to the existing Distributed Power management algorithm (DISPOW) in distributing the power. The algorithm noticeably enhances the performance of the system and improves average power and thermal noise of network's nodes for a certain situation by almost 0.05Watt and -5dBm, respectively.

Index Terms—Power control algorithm, DISPOW, LETPOW.

I. Introduction

A distributed power control approach is an important part in Mobile Ad hoc Networks that provides better network connectivity to achieve the good performance. The conventional approaches deal with this issue and that are classified into five main approaches: Node-Degree Constrained based, Graph Theory based, Game Theory based, Location Information based and Multi-Parameter Optimization based. One of the existing approaches [1] proposed adaptive distributed power management (DISPOW) algorithm based on the Multi-Parameter Optimization approach. This approach manages the transmit power of nodes through wireless ad hoc network. The proposed tailored stable network topology builds in distributed manner that preserves network connectivity and minimize the interference. Mutual Exclusion is one of the best solutions for resource sharing on distributed network. In [2] authors presented a new fully distributed token based mutual exclusion scheme for clustered MANETs which evaluate the performance of power optimization. Raymond’s algorithm is proposed for executing user jobs using FIFO queuing. The problem of proposed Raymond’s algorithm is unfair and not applicable for large scale distributed systems. Interference aware topology control in MANET is discussed in [3]. This is about Adaptive Distributed Power Management scheme that preserves network connectivity and reduce the interference adaptively in dynamic environment. If the SINR value is greater than the threshold, the noise interference between nodes attains low.

Energy conservation is an essential factor in DISPOW which focuses on [4] for location based topology control with sleep scheduling in MANETs. As a part of power management scheme, traffic conditions are considered and monitored continuously. Based on the traffic conditions, a node put into sleep state. More number of nodes are put into sleep state because a node with less energy and does not participate with transmission is goes to sleep state, and a node with more congestion is also goes to sleep state. Due to this effect, packet transmission rate is low when compared to the conventional schemes. To investigate the efficiency of nodes transmission power, a novel distributed transmission power control protocol was proposed in [5]. The proposed protocol called “Distributed Power Level (DPL) for multi-channel ad hoc networks that works without requiring clock synchronization. Two kinds of transmission modes are introduced in DPL: symmetrical mode and asymmetrical mode. In symmetrical mode, for selected channel the same power level is assigned and on other hand asymmetrical mode, the selected channel uses lower/equal power level for transmission. Typical MST based topology control schemes were introduced to control the network topology that used in wireless multi-hop networks. Due to the flexibility, the system leads to poor performance in terms of network capacity and transmission power [6]. Interference limited ad hoc network is proposed in the High SINR regime that scope is to optimise the network utility and improve the energy efficiency [7]. To this end, various strategies were invoked such as backpressure routing, interference, power cost, power control driven by backlog, local queue lengths, backpressure routing. In order to make the strong foundation of topology control and routing, in [8] proposed cross layer distributed algorithm for considering and overcomes the problems of interference with proposing two constraints such as delay constraint and interference constraint. Through this

Manuscript received December 16, 2017; revised May 10, 2018.
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doi:10.12720/jcm.13.5.236-241

algorithm unstable links are removed from the network topology. This leads to less packet delivery ratio and high routing overhead.

II. Link Expiration Time Aware Distributed Power Management Algorithm, LETPOW

A. Problem Definition

$P_{T_i}(t)$ and ζ (t) may be defined as the transmitting power and connectivity of node *i* at time t in the network of *k* nodes in an area A, then we need to select [3]

$$P_{T_K}(t) \; \forall \; node \; k \; in \; \{1,2,\dots,k\} \tag{1}$$

- There is a need for the node to have at least minimum connectivity with an acceptable number of neighbours facilitating a bi-directional link at any given time *t* [3].

$$\zeta_k(t) \geq \zeta_{k_{min}}(t) \;\; \forall \; node \; k \; in \; \{1,2,\dots,k\} \tag{2}$$

- In order to ensure a packet from node *j* to node *i* can be suitably identified, signal to interference and noise ratio at the latter node needs to be larger than a threshold.

$$SINR_t^l = \frac{h_l P_t^l}{\sigma W + \sum_{\substack{l' \in L \\ l' \neq l}} h(TX_l, RX_l) P_t^l} \; (\forall \; l \in L, t \in \Gamma) \tag{3}$$

where h_l propagation gain of link, σ thermal noise and *TX* denotes transmitter link and *RX* receive link, Γ represents total number of scheduled time slots, *L* referees sets of nodes causing interference, *W* is link capacity and P_t^l continuous time interval.
Furthermore, upon the node transmitting, this should not be at such a high level that it causes interference across other neighbouring nodes. In particular, there is a need to ensure the total noise power P_{k_i} in the node ***i*** is reduced, P_{K_i} the received power levels from node *k* to node ***i*** and σ thermal noise [3]

$$min \; P_{n_k} \; \forall \; node \; k \; in \; \{1,2,\dots,k\} \tag{4}$$

where $P_{n_k} = \sigma + \sum_{\substack{K \in N \\ K \neq j}} P_{K_i}(t)$

In addition, should a node be recognised as displaying high node connectivity, it might then be positioned to lower its transmitting power whilst still maintaining acceptable ζ. Let $\zeta_{i_{max}}$ be the maximum number of neighbors allowed, i.e. Text mode the upper acceptable connectivity threshold then should be set, which allows the benefit of decreasing inter-node interference in the network [3].

$$\zeta_k^t \leq \zeta_{k_{max}}^t \; \forall \; node \; k \; in \; \{1,2,\dots,k\} \tag{5}$$

- For node *i*, P_{T_k} should exceed the minimum power level, $P_{T_{imin}}$ although there is a need to ensure it is below the maximum power level. Importantly, $P_{T_{kmax}}$ needs to be defined in line with node power and network specifications [3].

$$P_{T_{kmin}} \leq P_{T_k}(t) \leq P_{T_{kmax}} \forall \; node \; k \; in \{1,2,\dots,k\} \tag{6}$$

Link expiration time l_k, also needs to be conserved through the use of the algorithm, which a critical design element needs to be incorporated within mobile ad-hoc networks. Importantly, nodes can increase their P_T only when their l_k greater than the threshold value $l_{threshold\ value}$ [3].

$$l_k \geq l_{threshold\ value} \; \forall \; node \; k \; in \; \{1,2,\dots,k\} \tag{7}$$

Should ζ_k be found to be lower than ζ_{kmin} for node k, then efforts will be made towards enhancing th $\zeta_k$through increasing overall P_{T_k}.Importantly, such an increase P_{T_k} can be achieved only if it is of a lower level than $P_{T_{kmax}}$. The node carries out a check to determine whether or not there are any unidirectional links from other nodes; should this be the case, it will seek to create bi-directional links with possible neighbouring nodes. Further, its P_{T_k} will be increased through an increment Δ*P* and carries out checks following a short delay, T_{short_delay} . Should there be none of these links, however, the node then can only create uni-directional links through increasing the overall P_{T_k}. Accordingly, it is just as essential for the possible neighbour to direct efforts towards creating a link. Accordingly, the node increases it's P_{T_k} and broadcasts a **PowerUp_Request**. At this point, it waits for medium time delay, T_{medium_delay} to determine whether or not it has been successful in establishing a new link. Owing to the fact it is trying to create links with non-neighbouring nodes, the greatest hop count for **PowerUp_Request** is **2**. This cannot be set overly high owing to the fact that nodes transmitting at high levels could induce interference amongst other nodes. Eventually, therefore, the lowest P_{T_k} will be chosen and thus will create a bi-directional link.

Should the node demonstrate movement into a denser arena, it then might be well positioned to lower its P_T whilst still maintaining an acceptable connectivity across the network. This provides the key benefit of decreasing network interference between nodes. Accordingly, should ζ_k be found to be greater than ζ_{kmax}, it has P_{T_k} would then be decreased, with its $\zeta_k$checked following T_{short_delay}. Furthermore, should it be found to be suffering from interference, node *k* will decide to broadcast **PowerDown_Request**. Accordingly, when detailing the request, it sets the maximum hop count to 2, as discussed earlier, so as to ensure forwarding overheads are prevented. Moreover, the Time-To-Live is also set Request TTL which ensures any older requests are disregarded.

Should a **PowerDown_Request** be received by a node, its P_k will be decreased should it's ζ_k be found to be at higer an acceptable range. Notably, upon making changes to its P_k, its ζ_k will be checked following the $T_{short\_delay.}$ Should this not be the case, the timer will be set to a long time delay T_{long_delay} so as to ensure an extreme number of calculations and overhead are avoided as a result of the frequent P_k changes. Should a **PowerUp_Request** be received, the P_k will be increased, but only if it's ζ_k is in the lower acceptable range. At this point, T_{short_delay} will be anticipated so as to determine ζ_k. Should the hop count and RequestTTL be found to be valid, a node then will forward other node requests. In any event, should l_k be found to be insufficient, i.e. less than $l_{kcritical}$ it then will reduce it's P_{T_k} so as to ensure ζ_{kmin} is maintained. This essentially means that the node battery and overall network lifetime will be prolonged.

B. Relationships of Node Connectivity with Node Density, Transmit Power and Physical Network Environment Ease of Use

If we were to choose node i as a reference code, the wireless channel propagation model can be modelled with the long distance path loss and fading propagation model. The rationale behind such selection can be seen in [9], where the propagation loss at the receiver d meter away from node i, when making the assumption of the presence of a unit reference distance do as delivered by the following [3]:

$$P_L = P_L(d_o) * d^{\eta} * L_{Fading}$$

$$P_L = P_L(d_o) + 10\eta \log(d)\, d^{\eta} + L_{Fading} \quad (8)$$

where L_{Fading} may be recognised as fading loss as a direct result of shadowing and Rayleigh fading effects, whilst η is the propagation path loss exponent and $P_L(d_o)$ is regarded as the reference path loss at do. In order to achieve a correct reception of packet P_{T_k} needs to be adequate in line with overcoming any degree of propagation loss whilst also satisfying receiver sensitivity P_{rs}. It is important to acknowledge that, in line with the 802.11 standard, in this paper, a link may be recognised as good or acceptable should the signal power in the receiving node be seen to be larger than the P_{rs} of –95 dBm. Career sense threshold effect in the case of topology control algorithms undergo examination in [3]. Subsequently, from (8), the following can be established [3]:

$$P_{T_k} dB \geq P_{rs}\, dB + P_L(d_o) + 10\eta \log(d) + L_{Fading} \quad (9)$$

For the sake of simplicity, the fading loss in (9) will be disregarded, with the effects of fading channel on topology control algorithms presented in [8] from an analytical perspective. Through the simplification of (9), the following is achieved [3]:

$$P_T \geq P_r + P_L(d_o) + 10\eta \log(d),$$

$$P_T \geq P_r + P_L(d_o) + d^{\eta},$$

$$d^{\eta} \leq \frac{P_T}{P_r * P_L(d_o)} = P_T * K = P_T(P_r * P_L(d))^{-1}$$

$$d \leq \sqrt[\eta]{KP_{T_i}} \quad (10)$$

where constant $(P_r * P_L(d))^{-1}$

Accordingly, if a random node l is to successfully receive the packet from node l, notably when transmitting with an omnidirectional antenna, node l needs to be present with in node is coverage area, which is recognised by a radius circle d, as presented through (10). If node density ρ, be acknowledged as the number of nodes in a unit square area, then the number of unidirectional neighbour of node i, specifically within its area of coverage, can be established through the following (11) [3]:

Total number of nodes area of circle:

$$neighbour = \left[\pi (k * P)^{\frac{2}{\eta}}\right] * \rho - 1$$

$$\zeta_k = \pi\lambda\, (aP_{t_k})^{\frac{2}{\nu}} \quad (11)$$

As is apparent, there is a direct dependence of ζ on ρ, as well as on P_T. There is a consistent increase with a greater number of nodes in the network, as shown in Fig. 1(a).

Furthermore, there is dependency of ζ on the physical network environment of the node through parameter η propagation. Such dependency's of the number of neighbour a node on the propagation environment as shown in Fig. 1(b). In Figs. 1(a,b) we comparison between proposed and DISPOW algorithms, the proposed algorithm can be observed that there is significant enhancement.

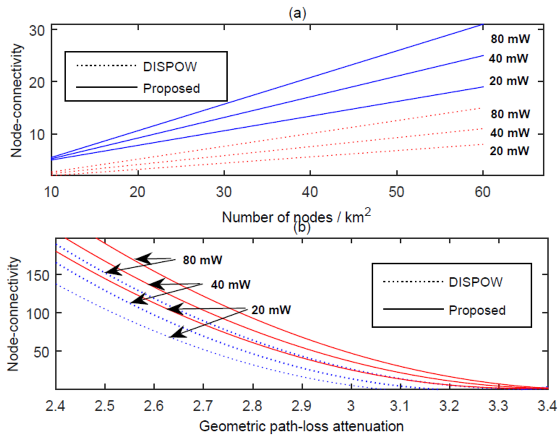

Fig. 1. Effect in node connectivity by changing its transmit power in different propagation environments.

The P_T of the node is adjusted by proposed algorithm (LETPOW) to maintain a minimum of ζ_{min}. As such, the mathematical lower bound P_{t_k} in guaranteeing ζ_{min} can be seen outlined below (12) [3]:

$$\zeta_k + 1 \geq \pi\rho (Kp_T)^{\frac{2}{\eta}}$$

$$\frac{\zeta_k + 1}{\pi\rho} \geq (Kp_T)^{\frac{2}{\eta}}$$

$$\frac{\zeta_k + 1}{\pi\rho} \geq Kp_T$$

$$P_T \geq \frac{\left(\frac{\zeta_k + 1}{\pi\rho}\right)^{\frac{2}{\eta}}}{K}$$

$$P_{T_k} \geq \frac{1}{K} \left(\frac{\zeta_{kmin+1}}{\pi\rho}\right)^{\frac{2}{\eta}} \quad (12)$$

Fig. 2(a) presents the way in which a node is able to maintain ζ_{min} through making changes to its P_T to σ and propagation environment. Fig. 2(b) that the average P_T increases with increasing attenuating environment. The average P_T also increases as ζ_{min} increases. Detailed analysis of power distribution shows that in low attenuating propagation environment most of the nodes have P_T less than the average P_T. It is the few nodes in the network that are physically isolated that raise the total node power in the network.

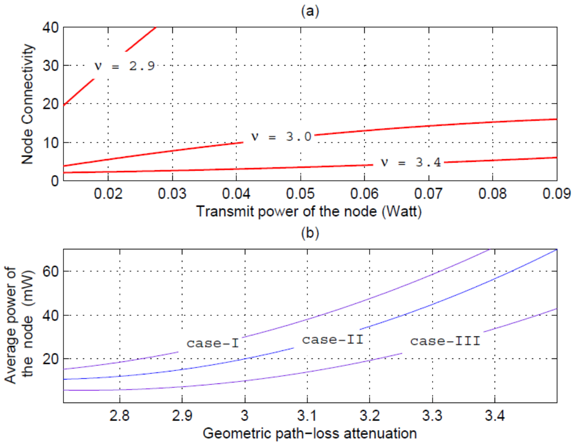

Fig. 2. Average node power over different propagation environment.

Assuming node i increases it's P_{T_k} by an increment, ΔP, in an attempt to build links with other nodes that is already not its neighbor in the network. Similarly, a node can also decrease it's P_{T_k} with ΔP possibly losing links with some of its neighbours and still maintains at least minimum connectivity, ζ_{min}. The consequent change in ζ_k because of these power level updates can be evaluated from (11) as (13) [3].

$$\Delta\zeta_k = \pi\rho k^{\frac{2}{\eta}}\left[(P_{T_k} \pm \Delta P)^{\frac{2}{\eta}} - (P_{T_k})^{\frac{2}{\eta}}\right] \tag{13}$$

LETPOW will keep the total noise floor below a threshold, Γ_{inf}, so that a transmitting node i does not overwhelm nearby nodes. Simplifying from (4) and (8), we have (14) [3]

$$P_T dB \le \Gamma_{inf}\, dB + 10\eta\log(d) + P_L(d_o) + P_o \tag{14}$$

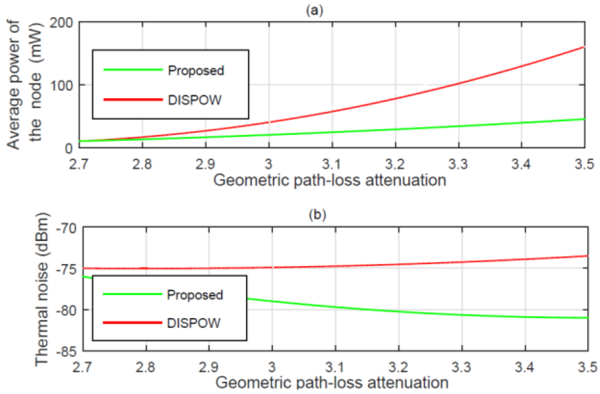

Fig. 3. Average node total noise floor with proposed algorithm and DISPOW with ζ of 1.

Fig. 3 (a) further analysis of P_T distribution with DISPOW and LETPOW algorithms, an increased average inherently implies an increase in inter-node interference. In addition to that, common power needed to connect isolated nodes can cause high interference in a denser part of the network. As shown in Fig. 3 (b) the average noise floor with DISPOW is much higher than that with LETPOW. It decreases in a higher attenuating environment because propagation distance of signals is limited. Higher average noise floor leads to higher power level and therefore more inter-node interference.

C. The Proposed Algorithm, LETPOW

In this algorithm, we periodically checks the node connectivity ζ, interference level, link expiration time l_k, node energy (ε), node mobility (m), and routing overhead (r). Let us assume that each node has no knowledge of other nodes P_T.

Algorithm 1. LETPOW

LETPOW. Node

Set $P_{T_k} = P_{T_{initial}}$, compute ζ_k *and* set timer $= T_{id}$, soft state timer T_k, Link expiration time=l_k, poer level (E_{ij}), node transmit fixed rate $=R$, energy = ε and node identifier $= n_{id}$.

If $\zeta_k \le \zeta_{k_{min}} \& \, l_{k_{min}}$ *then* **LETPOW. LowConnectivity**

Else

If $l_K < l_{k_{critical}} \& \, l_{k_{min}}$ **then LETPOW.Critical Battery Level**

Else

If $\zeta_k \le \zeta_{k_{max}} \& \, l_{k_{max}}$ *then* **LETPOW.High Connectivity**

Compute connectivity degree

$\zeta_{DEG\ k} = \frac{\zeta_k - \zeta_{k_{max}}}{\zeta_{k_{max}} - \zeta_{k_{min}}} + \frac{l_K - l_{k_{min}}}{l_{k_{max}} - l_{k_{min}}} + n_{id}$

Compute link expiration time factor $l_{FAC_K} = \frac{\varepsilon_k}{\varepsilon_r + N_o}$

Compute node mobility factor

$\boldsymbol{m}_{\ FAC_K} = (\boldsymbol{n_i} - \boldsymbol{n_j}) * \frac{1}{\varepsilon}$ *where* $\varepsilon > 0$

If Power Down_Request received, **then LETPOW.PowerDown_Request**

If PowerUp_Request received, **then LETPOW.PowerUp_Request**

If PowerOff_Request received, **then LETPOW.PowerOff_Request**

If suffering from interference **then LETPOW.Interference , Sleep until timer expires**

LETPOW. Low Connectivity

If $P_{T_k} < P_{T_{kmax}}$ **then ,** calculate $P_{T_k} = P_{T_k} + \Delta P$ and set timer τ_{sd}

Else

property (i)

If (i>j),(E_i ***and*** E_j Satisfy) **then**

$\log_2 = \left(1 + \frac{\varepsilon_i}{\varepsilon_j + N_o}\right) \ge R$

property (ii)

If (j>0),(E_j Satisfy) **then**

$\log_2 = \left(1 + \frac{\varepsilon_j}{N_o}\right) \geq R$

Else

set timer τ_{ld}

17: **If** No Asymmetric link to itself **then**
broadcast PowerUp_Request and set timer τ_{md}

LETPOW. High Connectivity

18: **If** $P_{T_k} > P_{T_{kmax}}$ **then ,** calculate
$P_{T_k} = P_{T_k} - \Delta P$ and set timer τ_{sd}

19: property (i)

If (i>j),(E_i ***and*** E_j Satisfy) **then**

$\log_2 = \left(1 + \frac{\varepsilon_i}{\varepsilon_j + N_o}\right) \geq R$

property (ii)

If (j>0),(E_j Satisfy) **then**

$\log_2 = \left(1 + \frac{\varepsilon_j}{N_o}\right) \geq R$

Else

set timer τ_{ld}

LETPOW. Interference

20: property (i)

If (i>j),(E_i ***and*** E_j Satisfy) **then**

$\log_2 = \left(1 + \frac{\varepsilon_i}{\varepsilon_j + N_o}\right) \geq R$

property (ii)

If (j>0),(E_j Satisfy) **then**

$\log_2 = \left(1 + \frac{\varepsilon_j}{N_o}\right) \geq R$

Else

set timer τ_{ld}

21: Set TTL and Hop Count

LETPOW.PowerUp_Request

22: **If** $\zeta_{DEG\ k}$ in high range, l_{FAC_K} in minimum
$and\ m_{FAC}$ minimum value , calculate
$P_{T_k} = P_{T_k} + \Delta P$ and set timer τ_{sd}

23: **Else**
set timer τ_{ld}

LETPOW.PowerDown_Request

24: **If** $\zeta_{DEG\ k}$ in high range, l_{FAC_K} in minimum
$and\ m_{FAC}$ minimum value , calculate
$P_{T_k} = P_{T_k} - \Delta P$ and set timer τ_{sd}

25: **Else**
set timer τ_{ld}

LETPOW.PowerOff_Request

26: **If** $\zeta_{DEG\ k}$ in lower range, l_{FAC_K} in minimum
$and\ m_{FAC}$ minimum value , calculate
$P_{T_k} = P_{T_k} - \Delta P$ and set timer τ_{sd}

27: **Else**
set timer τ_{ld}

LETPOW.CriticalBatteryLevel

28 **If** $\zeta_{DEG\ k}$ in high range, l_{FAC_K} in minimum
$and\ m_{FAC}$ minimum value , calculate
$P_{T_k} = P_{T_k} - \Delta P$ and set timer τ_{sd}

29 **Else**
set timer τ_{ld}

1. LETPOW. Node.

For node *i*, if ζ_k is less than ζ_{kmin} it will attempt to improve it's ζ. Similarly link expiration time $l_{k_{min}}$ hould be less value there by increasing power P_T if it is lower than $P_{T_{max}}$. The node checks if there are any unidirectional links from other nodes. If there are, it tries to build bi-directional links with those potential neighbour nodes. It increases its by an increment, ΔP and verifies only after attaining short time delay T_{short_delay} If there are no-unidirectional links to the node, then the node can only create uni-directional link by increasing its P_{T_k} and broadcasts a **PowerUp_Request**. It then waits for medium time delay, T_{medium_delay} .to check if it managed to set up any new link. Since it is trying to construct link with nodes that are not its neighbours, the maximum hop count for **PowerUp_Request** is set at 2. It should not be set too high because nodes transmitting at high P_{T_k} can interfere nearby nodes and also increased overhead. Thus it will eventually select the lowest P_{T_k} that will create bi-directional link.

2. LETPOW. lowConnectivity

Here assume that the node moves into a dense area, it can probably afford to reduce its P_T and still maintain acceptable network connectivity. This leads to an advantage of decreasing the interference between nodes in the network. Now If ζ_k is higher than $\zeta_{k_{max}}$, it decreases its P_T and checks its ζ_k after T_{short_delay}. Here two properties are introduced before broadcast the **PowerUp_Request**. The property(i) and property(ii) when two nodes transmitting simultaneously, as long as their chosen power levels (P_{T_k}) are different. If the less power value is consumed, thus we can attain the optimum throughput.

3. LETPOW. HighConnectivity

Here a node *i* will broadcast PowerDown_Request if it is suffering from interference. It sets maximum hop count for the request to 2 to prevent forwarding overhead. Older requests are ignored by Request_TTL (Time–To-Live). Here two properties is introduced before broadcast the **PowerDown_Request**. The property (i) and property(ii) when two nodes transmitting simultaneously, as long as their chosen power levels(P_{T_k}) are different. If the less power value is consumed, thus we can attain the optimum throughput

4. LETPOW.Interference

When the node receives a **PowerDown_Request**, it will reduce its P_K if $\zeta_k$is in a higher acceptable range. When it changes its ζ_k, it verifies it's ζ_k after T_{short_delay}. Otherwise, it sets the timer to long time T_{long_delay} , to avoid excessive calculations and overhead due to frequent changes in P_K . If it receives a PowerUp_Request, it increases its P_K only if it's ζ_k in the lower acceptable range. It then waits for T_{short_delay} to check its ζ_k. A node will forward other node requests if they have a valid request_TTL and hop count.

5. LETPOW.PowerDown_Request

For each **LETPOW**.PowerDown_Request, the connectivity degree in high range, link expiration time factor and mobility factor should be gets minimum value. If the condition is true, then we calculate the power level using $P_{T_k} = P_{T_k} - \Delta P$ and the set timer T_{short_delay}.

6. LETPOW.PowerUp_Request

For each **LETPOW**.PowerUp_Request, the connectivity degree in high range, link expiration time factor and mobility factor should be gets minimum value. If the condition is true, then we calculate the power level using $P_{T_k} = P_{T_k} + \Delta P$ and the set timer τ_{sd}.

7. LETPOW.PowerOff_Request

In this request, we checks the connectivity in low range, link expiration time factor and mobility factor should be gets minimum value. If the condition is true, then we calculate the power level using $P_{T_k} = P_{T_k} - \Delta P$ and the set timer T_{short_delay} .

8. LETPOW.CriticalBatteryLevel

When the node at any instance l_k is not sufficient, i.e. less than $l_{kcritical}$ and link expiration time factor and mobility factor should be gets minimum value, it will reduce it's P_{T_k} to maintain ζ_{kmin}. This has an effect of prolonging node battery and network life time.

III. CONCLUSIONS

The suggested algorithm is a Link Expiration Time Aware Distributed Power control algorithm (LETPOW). It is an important part of Mobile Ad hoc Networks that provides better network connectivity performance; we build the adaptively stable network in the distributed manner by using the LETPOW. In multi-parameter optimization approach (LETPOW), various parameters are considered such as connectivity, interference, energy consumption, routing overhead and node mobility information. Node mobility information is predicted with node position, speed, and movement direction angle. Along with this, nodes with neighbouring nodes distances have predicted.

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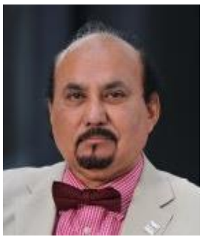

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