# Life Time Maximization of Homogeneous and Heterogeneous Ad Hoc Networks

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# Life Time Maximization of Homogeneous and Heterogeneous Ad Hoc Networks

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***Abstract*—In this paper, we address the problem of energy efficient routing in homogeneous and heterogeneous wireless ad hoc networks aiming at maximize the network lifetime. We define the network lifetime as the number of transmissions the node can perform until the first node fails due to battery exhaustion. In static networks we find a routing (spanning) tree which maximizes the network lifetime without tree update. We have proposed a Global weighted incremental power model and Global weighted post sweep for extending the life time of heterogeneous wireless ad hoc wireless network that gives better performance than the WBIP(Weighted Broadcast Incremental Protocol) implementation. We consider the amount of energy the node has compared to the maximum energy in network as the parameter in the cost metric function for constructing a efficient routing tree.**

***Index Terms*—Network Lifetime, Broadcast, Multi-cast, Wireless Adhoc Networks**

## I. Introduction

Mobile ad hoc networks are multi-hop, wireless, infrastructure less collection of self organizing mobile hosts that form a temporary cooperative network without the aid of any base station. The hosts are dynamic in nature i.e., they are free to move randomly, join or leave the network without notice and without disrupting the existing communication links. These networks can be created and used anywhere and anytime and intrinsically fault-resilient as they do not operate under a fixed topology.

Ad hoc networks find tremendous applications in tactical networking and disaster recovery operations such as communication in military operations in a hostile environment, establishment of communication infrastructure during law enforcement operations, sensors scattered for biological detection, space exploration, under water operations for setting up virtual classrooms, hospitals, communication in exhibitions, conferences or sales presentations.

In ad hoc networks, nodes have limited battery power and these nodes have the capacity to modify the area of coverage with their transmitting power and thereby reduce energy consumption and increase the lifetime of the network. However, reducing the transmitting power leads to the loss of connectivity. Hence, there is a need to maintain the connectivity of the network apart from reducing the redundant exchange of messages and extending the life time of the network, where all nodes co-operatively maintain network connectivity. Since considerable amount of expensive energy is utilized to transmit packets over long distances, short multi-hops are preferred to reduce the average energy requirements, resulting in large delay in delivery of packets. Moreover inadequate security and poor quality of service add to the problems of ad hoc networks.

Several power aware routing protocols and topology control algorithms have been developed; these aim to minimize the total energy consumed per packet during the transmission using the shortest path algorithm in which the edge costs are related to the power required to transmit a packet between two consecutive nodes. If a minimum energy path is found and all the traffic is routed through this path, then all nodes on this path will perish quickly, reducing the network lifetime. Many works using the linear programming approach attempt to address the energy consumption of nodes to maximize the network life time that are based on heuristic algorithms which perform badly in the worst case scenarios.

$Motivation$: The routing protocols in wireless ad hoc networks play a significant role in energy management and prolonging the lifetime of the network. If there is a large transmitting power at each node, then network connectivity is very high and delay is low, on account of smaller number of relay nodes between the source and destination.

In high density networks, nodes with high transmitting power may experience interference from many other nodes which can reduce the available bandwidth. In the case of a sparse topology, low transmitting power of the nodes can limit the network span and partition the network. It is essential to get the right transmitting power to augment the lifetime of the network without losing connectivity.

$Contributions$: We have proposed models for extending the life time of homogeneous and heterogeneous ad hoc networks. In static networks we find a routing (spanning) tree which maximizes the network lifetime without tree update. The Global Weighted Incremental Power (GWIP) Model and Global Weighted Incremental Post Sweep (GWIPS) are proposed that give better performance than the WBIP (Weighted Broadcast Incremental Protocol) implementations. The rest of the paper is organized as follows: Section II presents related work and the different power control schemes. Section III defines the system model. Section IV defines the problem and notations. Sections V and VI describes the proposed formulations for Homogeneous and Heterogeneous ad hoc networks. Numerical results and conclusions are presented in Sections VII and VIII.

## II. Literature Survey

Kang et.al [1] have proposed a center-oriented broadcast routing algorithm that is power efficient and can supply the complexity of design principles in wireless Ad hoc networks. In [2], the authors have presented a power efficient algorithm for broadcast routing tree construction called Greedy perimeter broadcast efficiency. The paper has comparable performance with the BIP (Broadcast Increment Power), but the complexity of the algorithm needs to be improved.

Cratigy et.al [3] have described a localized minimum energy broadcast protocol where each node requires only the knowledge of its distance to all its neighboring nodes, the performance is comparable to the best known globalized BIP algorithm that requires global network information. The energy needed in this protocol appears to be lower than other algorithms. The algorithm is based on the use of relative neighborhood graph that presumes connectivity and is defined in a localized manner.

Wan et.al [4] have explored geometric structures of Euclidean minimum spanning trees to route sessions along the low cost path and the performances comparable to that of Broadcast Incremental power (BIP) algorithm. This algorithm has not taken mobility into account. A minimum energy multicast problem in trees of MILP for wireless ad hoc networks has been designed in [5]. It has been simulated only for few nodes and in static environment. Kumar et.al [6] have explored the issues of lifetime in wireless sensor networks.

Shiva Prakash et.al have proposed an Intelligent Gateway Selection Heuristic which eliminates redundant gateways during Passive Clustering and reduce the number of rebroadcasts and have studied a number of peculiar cases of network topology, which are frequent in a mobile environment [7], [8]. Shiva Prakash et.al have proposed efficient topology management in [9], [10] and global incremental power models for life maximization have been presented in [11], [12].

## III. Network Model

### A. Wireless Communications Model

Given an ad hoc wireless network of a finite set of nodes, and a finite set of links, a link is said to exist between two nodes $i$ and $j$ if they are within the transmission range of each other. A node can either be a transmitter or a receiver or a relay node or all of the above. The connectivity of the network depends on the transmission power. We assume that each node can choose its power level, not to exceed some maximum value.

Let us assume the maximum range of communication denoted by $t_r$, is the same for all the nodes and that $d(i,j)$ is the distance between nodes $i$ and $j$. Then

$$L = \{(i,j) \mid d(i,j) \leq t_r\} \tag{1}$$

The defined graph is known as the unit disk graph and $t_r$ is the transmission radius. The neighbor set $N(i)$ of the vertex $i$ is defined as

$$N(i) = \{j \mid (i,j) \in L\} \tag{2}$$

The average degree of the network is the average number of neighbors of its nodes. Let us assume that the nodes can change their power of transmission to save energy. Then, the range of node $i \in N$ represents the maximum distance between node $i$ and node which can receive its transmission. The range of node $i \in N$ is denoted by $t_r(i)$ such that $0 \leq t_r(i) \leq t_r$. Therefore the graph induced by range $t_r$ is denoted by $l_r$ the edge set defined as follows:

$$l_r = \{i,j \mid d(i,j) \leq t_r(i)\} \tag{3}$$

In the path loss propagation model, the ratio of received signal power $P_j$ at distance $d_{ij}$ from transmitter to the power of the transmitted signal $P_i$ is obtained as follows.

$$\frac{P_j}{P_i} = \frac{C}{d_{ij}^{\alpha}} \tag{4}$$

Where, $C$ is the constant that is a function of the wavelength, antenna height and antenna gain and $\alpha$ is the path loss factor ranging from $2$ for line of sight, $4$ for others.

Let the transmission range between two consecutive relay nodes of the network be $t_r$, and the average path length of message in the ad hoc network be $l_p$. The expected number of hops $h_{sd}$ between source destination pair is given by

$$h_{sd} = \frac{l_p}{t_r} \tag{5}$$

The path length $l_p$ is a function of node density, mobility and traffic pattern of nodes and area of the coverage of the network. In the uniform traffic pattern, that considers bandwidth the source node chooses its relay nodes(immediate destinations) with equal probability. In the local traffic pattern that considers energy the relay nodes that are closer rather than the farther nodes are the most probable neighbors of the source nodes and results in minimum energy route between $sd$ pair. A $StaticNetwork$, is defined as wireless network that does not reconfigure over a time, a $DynamicNetwork$, is a wireless network that is configured over a period of time.

## IV. Problem definition

Given an ad hoc wireless network $G_w(N,L)$ of a finite set of nodes, N = $\{$ $n_1$, $n_2$, ....., $n_p$ $\}$ and a finite set of links L = $\{$ ( $n_i$, $n_j$ ) $\mid$ $n_i$, $n_j$ $\in N \wedge$ $n_i \neq n_j$ $\}$; a link is said to exist between two nodes $n_i$ and $n_j$ if they are within the transmission range of each other. The objective are to (i) Find a routing (spanning) tree which maximizes the static network lifetime without tree update. (ii) Maximize the lifetime of a heterogeneous ad hoc network.

The following notations are used in this algorithm.

- $T_{bip}$, Heuristically constructed tree in a greedy fashion over all possible trees.
- N, set of nodes and their locations.
- $P_{max}$, maximally allowed transmitting power of nodes.
- $l$, set of edges(links).
- $P_i$, Transmitting power of node $i$.
- $P_{total}$, total transmitting power of $T$.
- $E_i(t)$, energy of node $i$ at time $t$.
- $E_{max}$, maximum energy of the network

- $\alpha$, is the path loss factor.
- $E_{ik}$, energy spent by node $i$ for the $k$th update.
- $d_{ij}$, Euclidean distance between node $i$ and $j$.
- $T$, a directed spanning tree rooted at source node $S$.
- $N_i^P$, physical neighbor of node $i$, $N_i^P = \{k \mid 0 \leq d_{ik}^{\alpha} \leq Pi\}$.
- $N_i^l$, logical neighbor of node $i$, $N_i^l = \{j \mid (i,j) \in T_S\}$.
- $W_{ij}$, the weight of an edge $(x,y)$ for a weighted directed graph $G$.
- $L_S$, static network lifetime (SNL) of a broadcast network.

Pairwise transmitting power: Transmitting power of node $i$ to reach node $j$:

$$P_{ij} = d_{ij}^{\alpha} \qquad 2 \leq \alpha \leq 4 \tag{6}$$

Transmitting power of node $i$:

$$P_i = \max_{(i,j)\in T} \{d_{ij}^{\alpha}\} \;\; \forall i \in N \tag{7}$$

$$0 \leq P_i \leq P_{max}$$

Total Transmit power of the tree($T$):

$$P_{total} = \sum_{i \in N} P_i \tag{8}$$

If there is a path from given source $S$ to all other nodes, $N$ then network is said to be connected. Binary constraints:

$$l_{ij} = \begin{cases} 1 & \text{if a link belongs to } T \\ 0 & \text{otherwise} \end{cases}$$

$$CN = l_{ij} + l_{ij}^2 + ...... + l_{ij}^{|N|-1} \tag{9}$$

for each $j \in N$. If $CN_{ij} > 0$ the network is connected

Maximum energy of the node in the network $E_{max}$:

$$E_{max} = \max_{i \in N}(E_i) \tag{10}$$

## V. Maximizing Homogeneous Network Lifetime

We define a static network as a network in which the underlying routing structure is not self-reconfigurable or does not change over time. For a directed graph, a directed spanning tree rooted at a node. Since a spanning tree is the minimal graph structure supporting the network connectivity, it is intuitively clear that a topology which maximizes the network lifetime should be a tree. Given a spanning tree $T$, the actual transmit power assigned to the node $i$ is $P_i = \max_{j \in N_i^l}(P_{ij})$.

### A. Broadcast Incremental Power (BIP)

$$T_{bip} \cong \arg \min_{T \in G(N,l)} \sum_{(i,j)\in T} \Delta P_{ij} \tag{11}$$

The BIP algorithm constructs the tree using greedy approach and the wireless broadcast advantage. The algorithm is not globally optimal, incremental power is used as the cost metric. The total transmit power is same as the total incremental power, because the algorithm has been developed considering the edge cost and shown in Table.1.

TABLE I
Broadcast Incremental Power(BIP)

```
BIP()
begin
    T_bip = {S}, P_i = 0  ∀  i ∈ N

    While |T| ≠ |N|
    begin
        Find j ∉ T such that incremental power
        ΔP_ij = d_ij^α − P(i) is minimum, i ∈ T, j ∉ T
        T_bip = T_bip ∪ {j}
        Set P_i = P_i + ΔP_ij
        Set P_total = P_total + ΔP_ij
    end
end
```

### B. Weighted Broadcast Incremental Protocol (WBIP)

All the metrics above use greedy approach to extend the network lifetime, minimizing the transmitting power of the nodes. A time dependent tree at each instance of time is found with the following cost metric which include the current battery energy and the edge length [13].

$$T_{wbip} \cong \arg \min_{T \in G(N,l)} \sum_{(i,j)\in T} W_i \Delta P_{ij} \tag{12}$$

$$W_i = \frac{E_i(0)}{(E_i(0) - \sum_{k=0}^{n} E_{ik})} \tag{13}$$

The cost metric $C_{ij} = W_i \Delta P_{ij}$ that includes both remaining energy cost and the link based cost. $W_i$ represents the current energy of the node $i$ at time $t$ and denominator gives the energy at the start. If the node has high residual energy, $W_i$ decreases and has more probability to be assigned a greater transmitting power.

When trying to extend the network lifetime, it is critical to define what we mean by the lifetime of a network. In this paper, we adopt the definition of the network lifetime as the time to the first node failure due to battery depletion at the node. We assume the broadcast from the source node takes place at the beginning of the network initialization. The static network lifetime $L_S(T)$ corresponding to a tree $T$ refers to the lifetime, when the tree $T$ does not change once the tree is setup at the initialization phase.

Given $E_i(t)$, if node $i$ transmits to node $j$ using transmit power $P_{ij}$, the link $(i,j)$ can be supported up to $\frac{E_i}{P_{ij}}$ units of time. The residual link longevity of link(i,j) at time $t$ is:

$$RL_{ij}(t) = \frac{E_i(t)}{P_{ij}} \tag{14}$$

Residual node longevity of node $i$ at time $t$ such that

$$RN_i(t) = \frac{E_i(t)}{P_i(t)} = \frac{E_i(t)}{\max_{j \in N_i^l}(P_{ij})} = \min_{j \in N_i^l}(RL_{ij}(t)) \tag{15}$$

Optimal (maximum) static network lifetime over all possible spanning tree $T$ such that

$$L_S(T) = \max\{L_S(T) \mid T \subset G\} \quad (16)$$

This corresponds to minimum node longevity which in turn corresponds to minimum link longevity as shown below:

$$L_S(T) = \min_{i \in N}(RN_i(0) = \min_{i \in N}(\frac{E_i(0)}{P_i}) \cdots \quad (17)$$

$$\cdots = \min_{i \in N}(\min_{i \in N} RL_{ij}(0)) = \min_{(i,j) \in T}(RL_{ij}(0)) \quad (18)$$

Since the original Prim's algorithm is for a minimum spanning tree on an undirected graph, we call this algorithm as the Directed Minimum Spanning Tree (DMST). The DMST algorithm in conjunction with edge weight $W_{ij} = \frac{P_{ij}}{E_i(0)}$ as Maximum Static Network Lifetime (MSNL) algorithm. Note that MST (Minimum Spanning Tree) with edge weight $W_{ij} = P_{ij}$ provides the MINMAX transmit power solution. This is optimal only for unidirected graphs and hence is equivalent to MSNL. In general the solution obtained by MST is not optimal. Note that while MSNL algorithm achieves the maximum static network lifetime, it is not the best solution in terms of total transmit power with the same bottleneck edge constraint.

## VI. Maximizing Heterogeneous Network Lifetime

### *A. Total Energy Weighted Incremental Model (Recharge Model)*

The more powerful nodes called $anchors$ are utilized to disseminate GPS (or) location information through the nodes of the network. Powerful nodes like $anchors$, $gateways$ function as data collection points and access points, it is highly likely that their order of magnitude are more powerful than the tiny nodes in terms of battery capacity, radio transmitting range and processing power and some of these nodes can be recharged. So, we can imagine that more capable nodes can be mixed with normal nodes. However, the existing model assumes flat architecture where nodes possess homogeneous capability and nodes cannot be recharged.

$$W_i = \frac{E_{total}(i)}{(E_{total}(i) - \sum_{k=0}^{n} E_{ik})} \quad (19)$$

$$E_{total}(i) = E_{total}(i) + E_{recharge}(i) \quad (20)$$

$E_{recharge}(i)$ = Amount of Energy Recharged

We propose the model considering a network in which the nodes can be recharged. However, if the a node $i$ is recharged with $E_{recharge}(i)$ it becomes necessary for it to inform the source node on its new energy level, or the source node should request for the amount of energy recharged across all the nodes before running the procedure. The weight $W_i$ (node cost) is the fraction of total energy of the node to remaining energy, here the cost metric is the product of the distance and remaining energy as in the earlier case. Since the nodes have hardware registers to keep track of the total energy, which are finite in there maximum storage value, we encounter the problem of wrap around (i.e., after the maximum value of the register is reached it loops back to zero) since $E_{total}$ keeps on increasing monotonically on recharge.

TABLE II

Global Weight Incremental Power(GWIP)

```
GWIP()
begin
    T_bip = {S}, level(S) = 0, P_i = 0  ∀  i ∈ N

    While |T| ≠ |N|
    begin
        Find j ∉ T such that Global Weighted Incremental Power
        GW_i ΔP_ij is minimum, i ∈ T, j ∉ T
        T_gwip = T_gwip ∪ {j}
        Set P_i = P_i + d_ij^α − P_i
        Set P_total = P_total + d_ij^α − P_i
        level(j) = level(i) + 1
    end
end
```

### *B. Global Weighted Incremental Power (GWIP)*

The above proposed and existing methods based on initial energy or the total energy of the node do not provide an ideal solution for heterogeneous networks. Since, high capable nodes are not utilized effectively. We propose a model which gives a best effort heuristic solution for the problem stated, where nodes are weighted globally with maximum energy.

$$T_{gwip} \cong \arg \min_{T \in G(N,l)} \sum_{(i,j) \in T} GW_i \Delta P_{ij} \quad (21)$$

$$GW_i = \frac{E_{max}}{E(i)} \quad (22)$$

Here weight $GW_i$(node cost) is the fraction of maximum energy of the network to the energy at node $i$, Node cost is scaled globally. If a node has more energy it has a higher probability of being assigned a higher transmitting power, the algorithm is shown in Table II. However, the source node should request all the nodes for the current energy level available before the procedure is started.

### *C. Global Weight Incremental Post Sweep(GWIPS)*

The following notations are used in this algorithm.

- $level$, { $a_1$,$a_2$, .. .. .. $a_n$ } is a $N$ element vector, where $a_i$ represents level of node $i$.
- $ll_i$ = { k | nodes of level $i$ }
- $\pi(i)$ = { j | where $(i,j) \in T$ } parent of node i
- $h$ = $\max_{i \in N}\{level(i)\}$ is height of the tree.

The total transmitting power of some nodes can be further reduced and energy can be saved using the post sweep procedure described in Table III. After constructing the tree as from the above defined models, the procedure helps in removing the redundant hops using the wireless broadcast advantage and results in power savings. The random post sweep method was proposed in [14]. We propose a top-down Heuristic approach which reduces the hop count to the destination nodes, thereby reducing the delay and total transmitting power.

TABLE III

GLOBAL WEIGHT INCREMENTAL POST SWEEP

```
GWIPS()
begin
    Lev = 1
    while (Lev < h) do
        for Each r ∈ ll_i
        begin
            for Each x ∈ N
            begin
                if level(x) ≥ level(r), π(x) ≠ r
                    level(x) = level(r) + 1
                end
            end
        end
    Lev = Lev + 1
    h = max_{i∈N}(level(i))
    end
end
```

## VII. PERFORMANCE EVALUATIONS

The simulation results are obtained using MATLAB 6.5. In the simulation setup the nodes are placed in a 10x10 two-dimensional region and are randomly and uniformly distributed within the workspace. All the nodes have maximum energy $E_{max}$ varying from $100$ to $1000$ units. The nodes in the network are uniformly distributed. The distance between two nodes is by $Euclidean\ distance$. Path loss factors $\alpha = 2, 3, 4$ are considered independently for various simulations. The number of transmissions between updates $\Delta\ T$. Constant bit rate traffic model is used for broadcasting from source to destination. Maximum transmitting power is $P_{max} = \infty$. At every update, the amount of energy consumed for the transmissions is subtracted from the energy available.

For homogeneous networks total transmissions of the original BIP, MST and MSNL algorithms are compared in Fig. 1 at $100$ iterations at different path loss factor $\alpha = 4$. The total transmissions of MSNL is lower than other algorithms.

With the increase in number of nodes for the same two dimensional region (network density) average distance between the nodes reduces. Therefore, the transmitting power of the nodes reduces resulting in reduction of the total transmit power hence the lifetime (total number of transmissions) has to increase. This can be observed from Fig. 2.

For heterogeneous networks, applying the sweep procedure we get better results as shown in Fig. 3 for node density $N$ = $20$ and $75$ and $\alpha$ = $2$. Total transmissions of the WBIPS algorithms and the proposed GWIPS are compared at $100$ iterations for a path loss factor of $4$ in Fig. 4. We see that GWIPS performs better than the existing WBIPS (Weighted Broadcast Incremental Protocol with Post Sweep) algorithm.

Lifetime of the broadcast network increases as the update interval (transmissions between updates) is reduced because there will be a uniform utilization of energy across nodes. The energy expended across the nodes becomes highly uneven if the update interval is increased, thus reducing lifetime. With higher path loss factor $\alpha = 3, 4$, lifetime (total transmission) reduces, because the power expended for each transmission is very high ($d_{ij}^4 \gg d_{ij}^2$) this can be seen from Fig. 5. This is in account of removing the redundant edges using the sweep procedure resulting in reduction of total transmitting power and thereby maximizing the lifetime of the network.

With the increase in number of nodes for the same two dimensional region (network density) the average distance between the nodes reduces. Therefore, the transmitting power of the nodes reduces resulting in reduction of the total transmit power hence the lifetime (total number of transmissions) increases. This can be observed from Fig. 6.

To summarize, one of the factors is that in GWIP, the cost of the node is based on the ratio of current energy to the maximum energy of the network. Therefore, nodes with higher energy levels are assigned higher transmitting power. This is in contrast with a network having equal energy at all nodes without the facility of discharging, Hence, the superior performance of GWIP in comparison with the WBIP protocol.

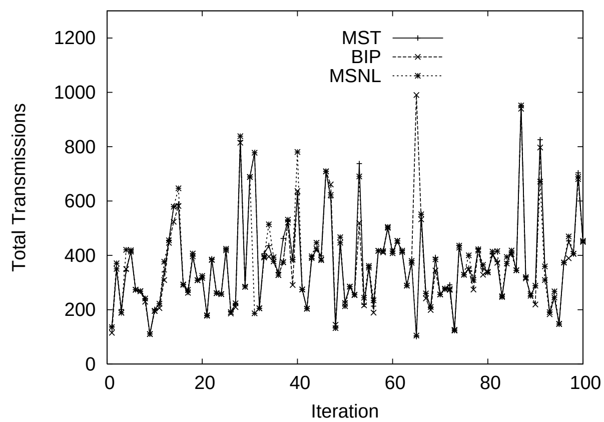


Fig. 1. Network Lifetime of MST, BIP and MSNL, Total Power for $\alpha$ = 4, $\delta$T = 15

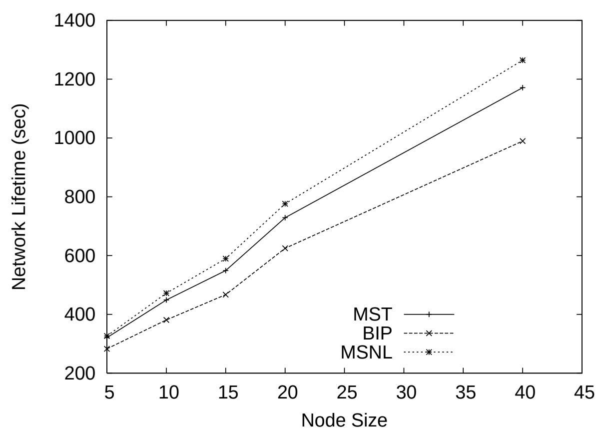


Fig. 2. Network Lifetime Vs Node Size of MST, BIP and MSNL, for $\alpha$ = 4, $\delta$T = 15

## VIII. CONCLUSIONS

We have considered the problem of power efficient broadcasting problem over homogeneous and heterogeneous wireless ad hoc networks to extend the network lifetime. In

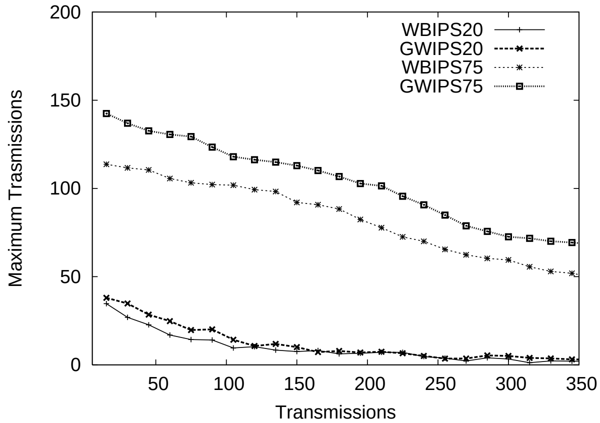


Fig. 3. Maximum Transmission Vs Transmissions $\Delta$ T=15.0,$\alpha$ = 2

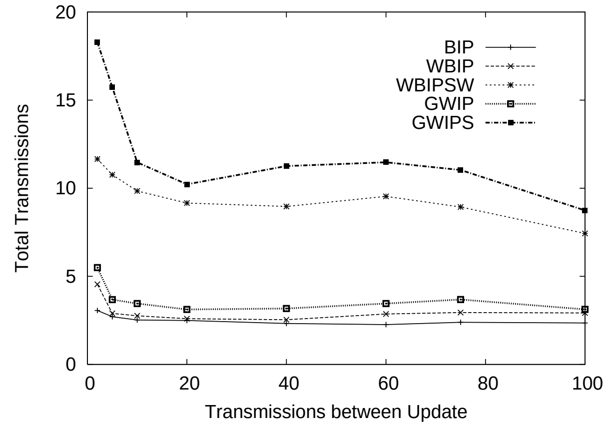


Fig. 5. Total Transmissions Vs $\Delta$ T=15.0: $\alpha$ = 4,N=15

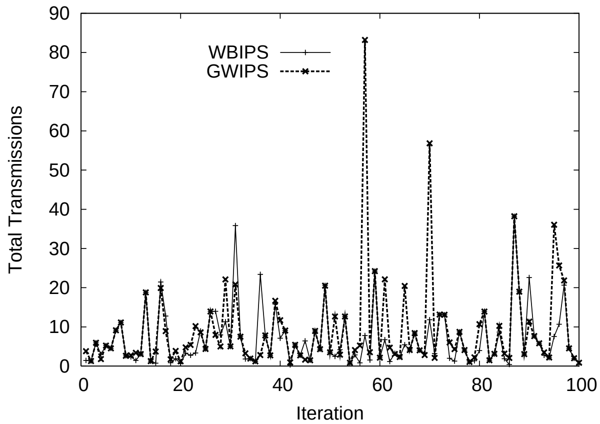


Fig. 4. Total Transmissions Vs Iteration $\alpha$=4, N=15, $\Delta$ T=15.0

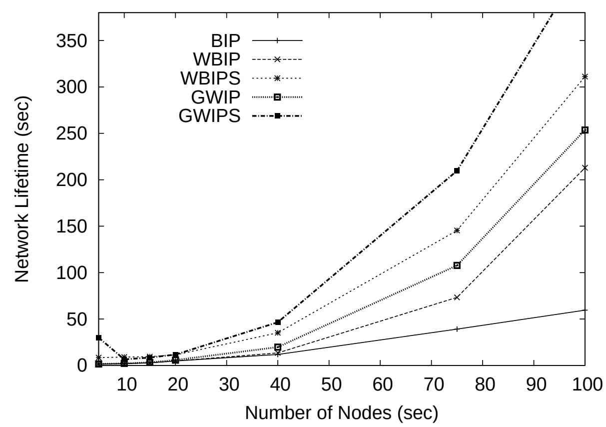


Fig. 6. Total Transmissions Vs Node Density $\alpha = 4$,$\Delta$ T=15.0

static networks we find a spanning tree which maximizes the network lifetime without tree update. We also propose a Global Weighted Incremental Power (GWIP) model and Global Weighted Incremental Sweep (GWIPS) procedure for heterogeneous networks. This model takes care of the problem of wrap around and uneven scaling of energy. Nodes are considered with varying energy capabilities from 100 to 1000 units. We observe that the total transmissions and energy utilization is much better than the earlier proposed BIP and WBIP algorithms.

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