Energy Efficient Routing Algorithm for MANETs

[Rama Devi Boddu [1], K. Kishan Rao [2], M. Asha Rani [3]]

***Abstract*— To meet the day to day challenges of wide usage of Mobile Ad hoc Networks (MANETs), energy efficient routing techniques is required to save battery power for a long network lifetime. In this paper, energy efficient Modified Bellman Ford Algorithm (MBFA) is proposed. The performance of a network depends on the node deployment. The network using two node deployment techniques, Grid topology (GT) and Random topology (RT) is implemented using QualNet Simulator. The proposed MBFA finds the shortest path using residual energy (RE) as a metric along with hop count and distance. Nodes in the network operate in Power Save Mode (PSM) using IEEE 802.11a/g Orthogonal Frequency Division Multiplexing (OFDM) standards of the Power Save Mechanism. PSM is energy efficient and improve network lifetime. Generic Radio Energy Model in QualNet Simulator is considered in route energy calculation. The performance of MBFA using fixed network traffic is investigated for both GT and RT. Simulation results show that the performance of GT using PSM is better when compared to RT. The energy consumed by MBFA with PSM is only 35-42% for static networks and 34-48% for mobile networks of MBFA without PSM.**

***Keywords*— Grid topology, MANETs, Modified Bellman Ford Algorithm, OFDM, Power Save Mode, Random topology.**

I. *Introduction*

Recent advances and usage of MANETs requires energy efficient routing techniques for efficient utilization of battery power to improve the network lifetime. MANETs require energy efficient, scalable, reliable routing protocols for multi-hop communication [1]. The lifetime of MANET is increased by saving energy of each node and this can be achieved by operating node in Power Save Mode (PSM). IEEE 802.11a/g Wireless Local Area Networks (WLAN) defines Power Save Mechanism [2] for both the Infrastructure and the Ad hoc mode which support both user mobility and high data rates. For MANETs, various power aware routing protocols using power saving were investigated [3-4].

Based on route calculation routing protocols are divided into: (i) Reactive (ii) Proactive and (iii) Hybrid routing protocols. In Reactive type, route is created on demand when the source is required to send a data packet to destination. In Proactive type, each node updates its routing table periodically with neighbour nodes and also updates the distance table. Distance Vector (DV) routing is a Proactive type routing protocol. The shortest path in DV routing is calculated by using two basic algorithms: (i) Bellman Ford Algorithm (BFA) and (ii) Dijkstra Algorithm. The BFA computes shortest paths from a single source vertex to all the other vertices in a weighted digraph. It is slower than Dijkstra's algorithm for the same problem, but more versatile, as it is capable of handling graphs in which some of the edge weights are negative numbers. Negative edge weights are found in various applications of graphs. When compared to Dijkstra Algorithm, BFA is free from routing loops for isotonic and non isotonic routing metric [5]. Because of these advantages BFA is being used in this research work. Several routing algorithms considering various routing metrics using BFA were available in the literature [6-7].

Node placement [8] affects the node density, network topology, routing, network delay, node energy, transmission range and the lifetime. Harish Shakywar et al. [9], Mohammad Matin [10] investigated energy considerations based on node placement and various routing protocols for the Grid placement model with varying network size.

In this paper, Grid and Random node placement strategies along with Power Save Mechanism of IEEE 802.11a/g using OFDM is considered. Energy efficient Modified Bellman Ford Algorithm (MBFA) is proposed which consider RE as a routing metric. The performance of static and mobile networks using proposed MBFA with PSM and without PSM is analyzed.

The paper is organized as follows: Section II describes System model and Routing, Section III explains proposed Modified Bellman Ford Algorithm. Energy consumed by the shortest route using MBFA is discussed in section IV. Simulation and results are analyzed in section V. Finally, section VI draws some conclusions and future works.

II. *System Model and Routing*

The wireless ad hoc network with n nodes is represented by a graph $G=(N,L_s)$ where L_s represents the link set and $N=(n_1,n_2,...n_n)$ represents a set of nodes. Let r be the transmission range of node n_i and the node n_j is within this transmission range if the distance between $(n_i,n_j)\le r$ and edge $e_{ij}=(n_i,n_j)\in L_s$. $C_{i,j}$ is the cost of direct edge e_{ij} and D_{n_i} represents the minimum cost from n_i to sink. The following assumptions are considered**:** (i) In Power Save Mode, when there is no data traffic mobile node enters into sleep or power down mode and save energy. (ii) All nodes have omnidirectional antennas with equal transmission power.

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(iii) All links between nodes are bidirectional. The iterative steps to find the shortest path in Distributive BFA is given by

$D_{n_i}^{h+1} = \min_{m \in N}[C_{m,n_i} + D_m^h]$, with initial conditions:

$D_1^h = 0$ for all h, $D_{n_i}^0 = \infty$ for all $i \neq 0$.

$i = 1, 2, ..., n$ and $h = 0, 1, 2, ...$ represents iteration value.

Distributive BFA terminates when $D_{n_i}^h = D_{n_i}^{h-1}$.

III. Modified Bellman Ford Algorithm

The proposed MBFA considers RE as a metric in addition to the hop count, distance and destination sequence of the routing table in the Distributive BFA. The implementation steps of MBFA are given below:

At the start of the simulation (Initialization step) all nodes are configured with a Distributive BFA and all nodes start broadcasting the route advertisement packets until each node gets the short distance to reach another node. In the same process the nodes communicate with the physical layer to get the energy of the respective node and that energy will be included in the routing table as a metric in its own route entry. The nodes whose change in Battery Capacity greater than the threshold value is not considered for routing to avoid frequent link failures due to battery leakage. The battery discharge loss and energy consumed by the processor are to be included in energy calculation. The above process continues until all the nodes include their energy in their routing table. When a source node wants to send a data packet to the destination node, it consults its routing table and finds the shortest route towards the destination. While forwarding the data packet, it calculates the energy of the route by summing the individual energies of all the nodes in the route. As the simulation continues to run, the nodes get discharged gradually so that nodes will update their energy periodically with the help of route update packets in which each node will include its updated energy as one field and broadcast to other nodes, where other nodes will include the updated energy in their routing table for each node. Thus, finally all the nodes are aware of the energies of all other nodes.

IV. Energy Calculation

MANET can be implemented by using IEEE 802.11 a/g standards. The transmitter and receiver circuit of a node using IEEE 802.11 a/g OFDM physical layer is shown in Figure 1. All nodes operate in multi modes (active, sleep, idle) using IEEE 802.11 Power Save Mechanism.

Let us consider a packet of L bits is transmitted in a maximum time T and time spent in active mode (T_{on}), sleep mode (T_{sp}), idle mode (T_{idle}). The time spend by the transceiver in active mode is $T_{on} \leq T$. T_{on} represents the time spent in active mode during transmission (T_{tx}) or reception (T_{rx}) or both $T_{on} = T_{tx} + T_{rx}$.

The transmission period T can be given [4] by

$$T = T_{on} + T_{sp} + T_{idle}. \quad (1)$$

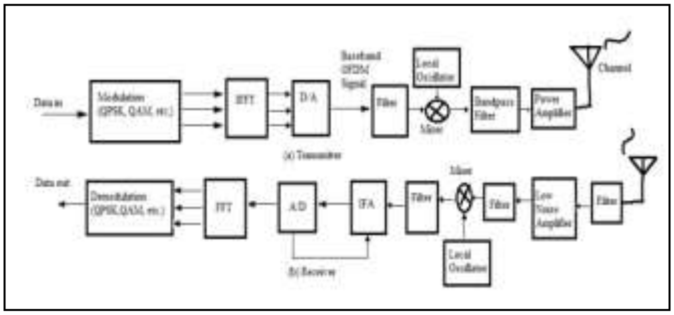

Figure 1. *Transmitter and receiver circuit using OFDM Physical layer*

In this section, the following representations are considered: Local transmission distance (d_m), path loss coefficient (α'), transmitter antenna gain (G_t), receiver antenna gain (G_r), link margin (M_l), receiver noise figure (N_f), average energy per bit required for given BER ($\bar{E}_b$), system bit rate (R_b), carrier wavelength (λ), maximum drain efficiency ($\eta_{\max}$), peak-to- average power ration (ξ), $\eta = \frac{\eta_{\max}}{\xi}$ and $\alpha = \frac{\xi}{\eta} - 1$. The powers consumed by the various blocks are: mixer (P_{mix}), a synthesizer (P_{syn}), transmitting filter (P_{filt}), receiving filter (P_{filr}), analog-to-digital (A/D) converter (P_{ADC}), digital-to-analog (D/A) converter (P_{DAC}), an intermediate frequency amplifier (P_{IFA}).

Let $P_t, \alpha P_t, P_{ct}, P_{cr}$ represents transmitted signal power, amplifier power, circuit power at the transmitter, circuit power at the receiver respectively and can be given [11] by

$$P_t = \frac{(4\pi)^2 d_m^{\alpha'} M_l N_f}{G_t G_r \lambda^2} \bar{E}_b R_b . \quad (2)$$

$$P_{ct} = P_{mix} + P_{syn} + P_{filt} + P_{DAC} . \quad (3)$$

$$P_{cr} = P_{mix} + P_{syn} + P_{LNA} + P_{filr} + P_{IFA} + P_{ADC} . \quad (4)$$

The power consumed in active mode during transmission (P_{tx}) can be calculated [12] by

$$P_{tx} = P_t + \alpha P_t + P_{ct} = (1+\alpha)P_t + P_{ct} = \frac{\xi}{\eta} P_t + P_{ct} . \quad (5)$$

The power consumed in active mode during reception (P_{rx}) can be given [12] by

$$P_{rx} = P_{cr} . \quad (6)$$

A. Residual Energy at a Node

Let E_k^i represents initial energy of a node n_k, the energy consumed by at node n_k for transmitting (E_k^{Tx}) or receiving (E_k^{Rx}) L bits are given [13] by

$$E_k^{Tx} = P_{tx}T_{tx} = \frac{\xi}{\eta}P_t + P_{ct} . \quad (7)$$

$$E_k^{Rx} = P_{rx}T_{rx} = P_{cr}T_{rx} . \quad (8)$$

After transmitting L bits, the RE (E_k^R) at a node n_k is given [13] by

$$E_k^R = \begin{cases} E_k^i - E_k^{Tx} \\ E_k^i - E_k^{Rx} \end{cases} . \quad (9)$$

B. Total Energy Consumed per Cycle

The total energy consumed at node n_k to transmit L bits in a cycle of a period (T) includes energy consumed in active mode by the transceiver at the radio frequency stage, idle and sleep modes, energy consumed at the baseband stage for signal processing or at CPU (E^{CPU}), battery discharge loss (E^{Bat}), DC-DC converter losses (E^{DC}) and can be expressed as

$$E_k = P_{on}T_{on} + P_{sp}T_{sp} + P_{idle}T_{idle} + E^{CPU} + E^{Bat} + E^{DC} . \quad (10)$$

$$E_k = P_{tx}T_{tx} + P_{rx}T_{rx} + P_{sp}T_{sp} + P_{idle}T_{idle} + E^{CPU} + E^{Bat} + E^{DC} . \quad (11)$$

RE at a node n_k after one cycle T is given by

$$E_k^R = E_k^i - E_k . \quad (12)$$

C. Total energy consumed by the shortest route using MBFA

Let $n_l(n_0, n_1, ..., n_z)$ represent the selected nodes in the shortest route using MBFA where n_0, n_z represents the source, destination nodes respectively and Z represents the number of hops. The total energy consumed per cycle by the shortest path using MBFA includes energy consumed by the transceiver, CPU energy, battery discharge loss, DC-DC converter losses. The total energy consumed per cycle by the shortest route through the node's $n_l(n_{l0}, n_{l1}, ..., n_{lz})$ using MBFA having Z hops can be expressed as

$$E_T = \sum_{l=0}^{Z-1}[(E_l^{Tx} + E_{l+1}^{Rx})\ ] + \sum_{l=0}^{Z}\left[E_l^{idle} + E_l^{CPU} + E_l^{Bat} + E_l^{DC}\right] . \quad (13)$$

where $E_l^{idel} = P_{idle}T_{idle}$ at node n_l and $P_{sp} \approx 0$ (neglected).

V. Simulation and Results

The scenario in 1000 square meter area for two different GT and RT are considered with different node densities 15,30,45,60. The simulation parameters used are: battery capacity 120 mAh, 64-QAM modulation, group mobility speed 2 m/s, path loss coefficient 2.3, transmit power 100 mW, receive power 130 mW, idle power 120 mW, initial node energy 6480 J and 1.2 Ahr with 1.5 V battery, radio range 217 - 402 m, data packet size 512 bytes, radio frequency 2.4 GHz, bandwidth 20 KHz, simulation time 3000 s. Under each topology experiment with a fixed and mobile network is tested for a fixed traffic network with PSM and without PSM to analyze the energy efficiency of the network using MBFA. In QualNet Simulator, PSM of operation is already being implemented (inbuilt). So we have used the default parameters relating to PSM: Beacon interval 200 TUs, ATIM interval 20 TUs where 1 Time Unit (TU) is 1024 µs. The BER Reception model is considered in all the test cases which is a basis for cooperative routing. Finally, for all the test cases the results are summarized and plotted. Generic Radio Energy Model in QualNet [14] is used for energy calculation with power consumption of mixer 30.3 mW, filter 2.5 mW, synthesizer 50 mW, LNA 20 mW, D/A converter 15.4 mW, A/D converter 14 mW, IFA 3 mW.

The performance of Distributive BFA and MBFA without PSM is compared [13] for varying network traffic. From the simulation results, it is observed the performance of MBFA is better when compared to Distributive BFA. The impact of mobility and Power Save Mechanism using GT and RT with different network sizes 15, 30, 45 and 60 is investigated. From the results it is observed that, the performance of a static network is better compared to the mobile network and static network has more Residual Battery Capacity (RBC).

In this paper, the network with the fixed traffic condition using MBFA is considered for research. The performance of MBFA for Multiple Sources and Multiple Destinations (MSMD) with Fixed Network Traffic (FNT) using 3 Sources and 3 Destinations is plotted below.

Total Packets Received: The total number of packets received using MBFA with and without PSM is plotted in Fig. 2. In a fixed traffic network, the available routes increase when the size of the network increases and the proposed algorithm select the best route to transmit the packet. Hence, as the size of the network increases the number of packets received in MBFA increases due to the best optimal path selection as shown in Figure 2. The number of packets received for GT is more than RT. Due to node mobility the number of packets is reduced and the number of packets received in the static network is more than the mobile network. In GT, the number of packets received is more compared to RT.

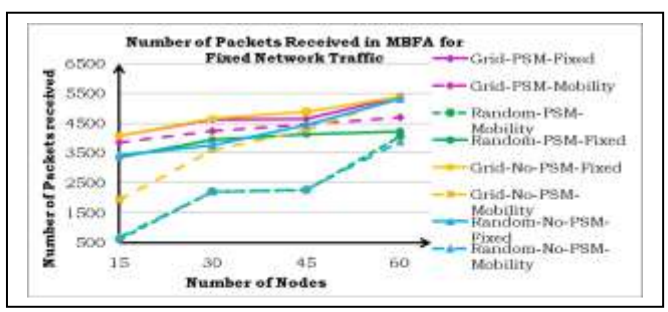

Figure 2. *Total Packet Received verses Number of nodes in MBFA with FNT*

Average End-to-End Delay: It is a measure of the average time taken for a packet to be transmitted across a network from Source to Destination. The possible routes increase with the number of nodes and MBFA selects an optimal route to forward the packet. The fixed traffic network using MBFA without PSM has less delay as shown in Figure 3. In MBFA, as the network size increases the end-to-end delay increases with PSM as shown in Figure 4. Static and mobile networks with PSM have more delay compared to without PSM.

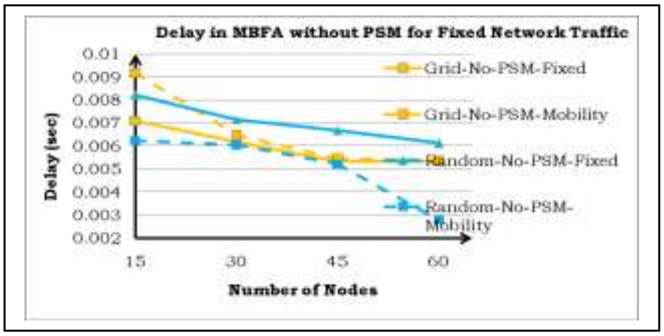

Figure 3. Delay verses Number of nodes in MBFA without PSM for FNT

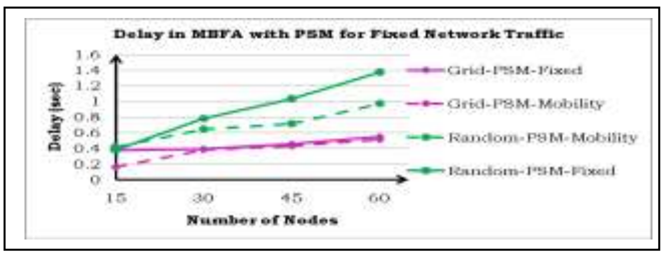

Figure 4. *Delay verses Number of nodes in MBFA with PSM for FNT*

Average Jitter: The variation of the inter-arrival times between the two successive packets received is defined as the average jitter. An average jitter in MBFA with and without PSM for the fixed network traffic is shown in Figure 5 and Figure 6. Average jitter is more for both static and mobile networks with PSM compared to without PSM.

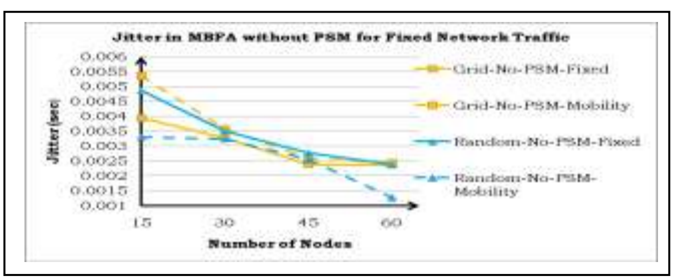

Figure 5. *Average Jitter verses Number of nodes in MBFA for without PSM*

Energy consumed in MBFA with Fixed Network Traffic: The energy consumed for the GT and RT with PSM and without PSM for a fixed network traffic is shown in the Figure 7. As the size of the network increases the MBFA finds optimal route to forward the packet and the energy consumption will decrease. In GT, the mobile network consumes more energy due to mobility of nodes. The GT and RT using MBFA without PSM consume more energy compared to with PSM. In PSM nodes will enter into sleep mode and save energy. The energy consumed by MBFA with PSM is only 35-42% for static networks and 34-48% for mobile networks of without PSM.

For the static network, energy consumed using MBFA for GT is less when compared to RT and GT has more RE compared to RT. In GT, the static network has a more RBC compared to the mobile network. The transmitted energy consumed depends on the distance between the nodes and increase with distance. In GT, mobility of the node increases the distance between the nodes, which increase the transmitted energy. Hence, the static network has more RBC when compared to the mobile network. A Random Way Point Mobility Model is used for mobility. The performance of a GT is better compared to RT and the static network has a more RBC compared to the mobile network. Some packets are lost in a mobile network due to node mobility and the performance degrades further using PSM.

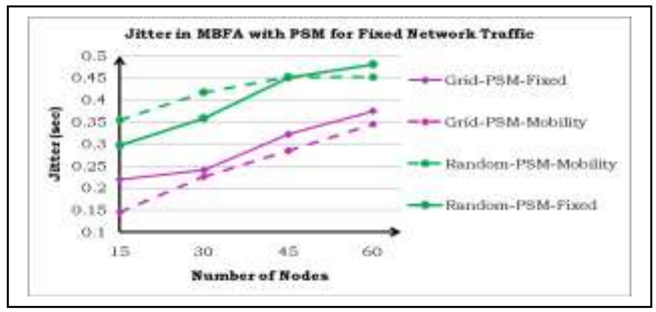

Figure 6. *Average Jitter verses Number of nodes in MBFA for PSM*

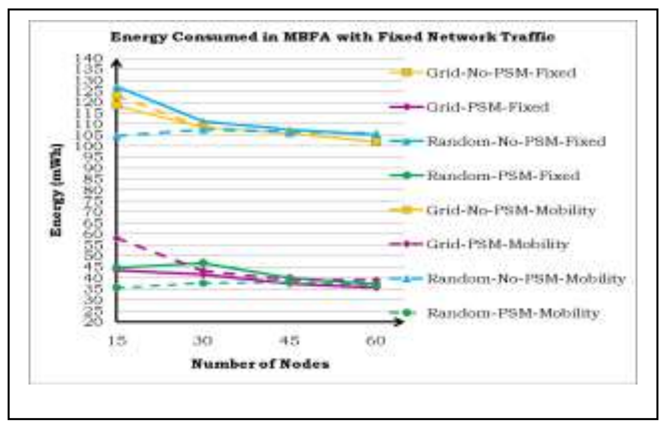

Figure 7. *Energy Consumed in MBFA using Fixed Network Traffic*

VI. *Conclusions*

Using QualNet, the performance of static and mobile nodes for with and without Power Save Mode in Grid and Random topologies using proposed Modified Bellman Ford Algorithm is evaluated for different network sizes.

For fixed network traffic, the routes available in a network increases with the increase in network size and the packet is forwarded in Modified Bellman Ford Algorithm through the best optimal energy efficient path. The number of packets received increases with the size of the network and energy consumed is reduced due to an optimal route is used to forward the packet. The Grid topology consumes less energy when compared to Random topology and network with Grid topology has more residual energy when compared to Random topology.

The energy consumed by Modified Bellman Ford Algorithm with Power Save Mode is only 35-42% for static networks and 34-48% for mobile networks of without Power Save Mode.

From different analyses of graphs and simulations, it is concluded that for MANETs Power Save Mode, Grid topology is energy efficient and suitable for Grid topology. We can also extend this research to cooperative communication. The performance of the MANETs can be enhanced by using Cooperative routing.

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