Energy-Efficient Modified Bellman Ford Algorithm for Grid and Random Network Topologies

Rama Devi Boddu, K. Kishan Rao and M. Asha Rani

Abstract Energy-efficient routing techniques are required for mobile ad hoc Networks (MANETs) to improve the lifetime of the network. The lifetime of the network depends on the battery capacity of nodes. The link failure due to the battery discharge of node can be avoided by considering the nodes having good residual energy (RE) with less change in their battery capacity. In this paper, the Bellman–Ford algorithm (BFA) is considered to find the shortest path for routing. Bellman–Ford algorithm is modified and the nodes whose change in battery capacity is less than a predefined threshold value are considered for routing to avoid the link failures and to enhance the lifetime of the network. In the proposed modified Bellman–Ford algorithm (MBFA), residual energy (RE) is considered as a metric to find the shortest path. IEEE 802.11 a/g standards using orthogonal frequency division multiplexing (OFDM) are considered for simulation. Energy consumed by the radio transceiver, processor, losses in the battery, and DC–DC converter are taken into consideration for energy calculation. The performance of BFA and MBFA for the grid and random network topologies is simulated by considering the network with multiple sources and destinations are compared with and without mobility by assuming various densities, i.e., 15, 30, 45, and 60. The mobility of the node increases the loss of orthogonality among the OFDM subcarriers and results inter carrier interference (ICI). The effect of mobility and network size on

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throughput, delay, jitters for the grid, and random network topologies using BFA and MBFA are compared. Simulation results show that the performance of proposed MBFA is better compared to BFA.

Keywords Bellman ford algorithm · Inter carrier interference · Modified bellman ford algorithm · OFDM · Residual energy

1 Introduction

The increase in demand and usage of mobile ad hoc networks in the present generation has to concentrate on the battery power usage of nodes in the ad hoc networks. For the efficient usage of battery power, we require an energy-efficient routing algorithm to improve the lifetime of the network. Minimum total power routing (MTPR) use distributed Bellman–Ford algorithm (BFA) and the path with a minimum total power cost from the source node to the current node is selected. In the minimum battery cost routing (MBCR) [1] route with maximum remaining battery capacity is selected to prevent overuse of nodes. Route in min-max battery cost routing (MMBCR) selects the route using MBCR by considering the battery capacity above the threshold. Toh et al. [2] proposed power aware conditional max-min battery capacity routing for a wireless ad hoc networks. A modified version of BFA was proposed to find out the shortest path using maximum residual energy (RE) [3] to improve the network lifetime. Neyre Tekbiyik et al. [4] presented a review on energy-efficient routing, link cost based, and an energy-efficient shortest path routing algorithms. Mostafa Dehghan et al. [5] developed an opportunistic routing algorithm and computed the optimum path using the stochastic version of BFA. Efficient Power Routing [6] considered energy consumption metric and battery discharging loss.

Node placement [7] affects the node density, network topology, routing, network delay, node energy and lifetime, and transmission range. Node placement can be classified into: (i) Deterministic (ii) Semi-deterministic (iii) Non-deterministic types [8]. Energy considerations based on node placement and various routing protocols for the grid topology with varying network size were investigated [9].

In this paper, the effect of node deployment with mobility and varying network size is considered (i) to propose energy-efficient routing algorithm and to investigate the effect of node deployment on its performance (ii) to analyze the performance of the grid and random networks with and without mobility with varying network size.

This paper is organized as follows: Sect. 2 describes energy consumption of OFDM transceiver; Sect. 3 describes proposed modified Bellman–Ford algorithm and energy calculation. Numerical results are analyzed in Sect. 4. Finally, conclusions are drawn in Sect. 5.

2 Energy Consumption in IEEE 802.11a/g OFDM Transceiver

The optimum energy consumed by the node can be calculated by considering all the blocks of transceiver circuit as shown in Fig. 1. Let us assume $P_{\text{PA}}, P_{\text{ct}}, P_{\text{ADC}}, P_{\text{mix}}$, P_{LNA}, P_{IFA}, P_{DAC}, P_{syn} , P_{filt} and P_{filr} represents power consumed by power amplifier (PA), circuit, analog-to-digital converter (ADC), mixer, low-noise amplifier (LNA), intermediate frequency amplifier (IFA), digital-to-analog converter (DAC), frequency synthesizer, active filter at transmitter, and receiver, respectively.

Power consumed by the node in active mode can be written as

$$P_{\text{on}} = P_{\text{PA}} + P_{\text{ct}} \tag{1}$$

Power consumed by PA is a function of transmission power P_{out} and is given by

$$P_{\text{PA}} = (1 + \alpha')P_{\text{out}} = \frac{\xi}{\eta} P_{\text{out}}, \tag{2}$$

where $\alpha' = \frac{\xi}{\eta} - 1$. $\eta = \frac{\eta_{\max}}{\xi}$ is drain efficiency of the power amplifier, $\eta_{\max}$ = maximum drain efficiency, ξ = peak to average ratio (PAR).

Transmission power is a function of distance and can be written as [10]

$$P_{\text{out}} = \bar{E}_b R_b \left[\frac{(4\pi)^2 d^{\alpha}}{G_r G_t \lambda^2} \right] M_l N_f, \tag{3}$$

where G_t, G_r represents gain of transmitting and receiving antennas, respectively; d is the distance between transmitter and receiver; $R_b, \lambda, M_l, \alpha, N_f, \bar{E}_b$ represents bit rate, carrier wavelength, link margin, path loss coefficient, noise figure, and energy required per bit per hop for a given symbol error rate, respectively.

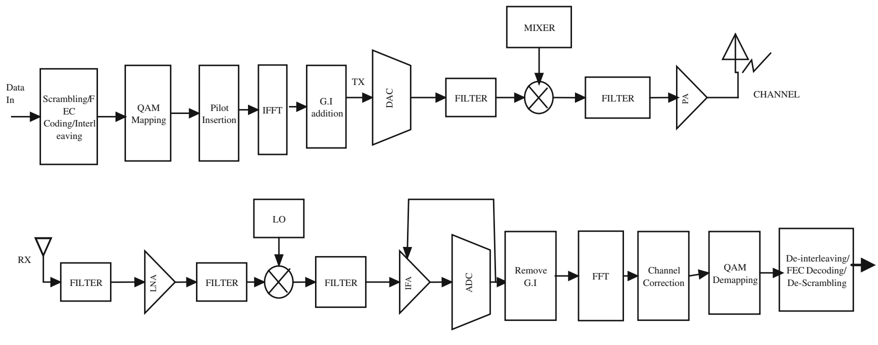

Fig. 1 OFDM transmitter and receiver with transceiver circuit

The total power consumed by the circuit (P_{ct}) is the sum of circuit power consumed at transmitting node (P_{ctx}) and receiving node (P_{ctr}).

$$P_{\text{ctx}} = P_{\text{DAC}} + P_{\text{mix}} + P_{\text{filt}} + P_{\text{syn}} \tag{4}$$

$$P_{\text{crx}} = P_{\text{LNA}} + P_{\text{mix}} + P_{\text{IFA}} + P_{\text{ADC}} + P_{\text{syn}} + P_{\text{filr}} \tag{5}$$

3 Proposed Modified Bellman Ford Algorithm

The wireless ad hoc network consists of n nodes represented by a node set $N = (n_1, n_2, n_3, \ldots n_n)$. The network was represented by a graph $G = (N, L)$, L represents the link set, $C_{i,j}$ represents the cost of direct edge $e_{i,j}$ between (n_i, n_j) and D_{n_i} represents the minimum cost from n_i to sink. BFA computes the shortest path using a distance vector routing protocol. Route update messages will be sent periodically to update the routing table. Shortest path using the BFA was evaluated [11] using the following iterative steps:

- Initialize with $D_1^h = 0$ for all h, $D_i^0 = \infty$ for all $i = 2, 3, .., n$
- Calculate $D_i^{h+1} = \min\limits_{j \in N}[C_{ij} + D_j^h]$ for all $i \neq 1$

  Let $h = h + 1$
- Bellman–Ford Algorithm terminates when $D_i^h = D_i^{h-1}$.

Modified Bellman–Ford Algorithm (*MFBA*): In MFBA, residual energy (RE) is considered as a metric in the routing table of BFA in addition to the destination sequence which was the standard metric. Initially, all nodes configured with BFA and broadcast the route advertisement packet to find the shortest distance to reach other node. Meanwhile, all nodes update their energies in the routing table as a route metric by communicating with the physical layer. When the new route advertisement packet arrives, the energy in the incoming route advertisement packet is compared with the energy of the node in the route table for which the packet is being advertised. The route table is updated when its energy is changed by the certain offset. To eliminate the nodes with the leakage battery capacity, always it checks the change in the battery capacity of a node is greater than the threshold or not. When a source node wants to transmit the packet, it finds the optimal path toward the destination by consulting the routing table. During the phase of packet forwarding, we can calculate the total energy consumed by the route has a sum of all hops, individual node energies present in the route, efficiency losses in the battery, energy consumed by the processor, and DC–DC converter are also to be considered. All the nodes in the route of MBFA are aware of the total energy utilized by that route. During the simulation, the nodes gradually get discharged and update their energies periodically with the help of route update packets and include in the routing table. Finally, all the nodes are aware of the energies of all other nodes.

Energy Calculation for MBFA: Let $E_{\text{tras\_amp}} d^{\alpha}_{k,k+1}$ represents transmission energy required to transmit a distance of $d_{k,k+1}$ between the nodes n_k to n_{k+1}; $E_{\text{trans\_Tx}}, E_{\text{trans\_Rx}}, E_{\text{Idle}}$ represents energy consumed by the transceiver circuit during transmission, reception, Idle state, respectively. Node initial energy is represented by E^i_k. The energy consumed by the processor, the efficiency losses in the battery and DC–DC converter are represented by $E_{\text{CPU}}, E_{\text{Bat}}, E_{\text{DC}}$, respectively.

The energy consumed to transmit a data packet of L bits from node n_k to n_{k+1} can be given by

$$\begin{aligned} E^{Tx}_k &= E_{\text{trans\_Tx}} + E_{\text{tras\_amp}} d^{\alpha}_{k,k+1} \\ &= P_{\text{ctx}} T_{\text{on}} + \frac{\xi}{\eta} \bar{E}_b R_b \left[\frac{(4\pi)^2}{G_r G_t \lambda^2} \right] M_l N_f \, T_{\text{on}} d^{\alpha}_{k,k+1} \end{aligned} \tag{6}$$

The energy consumed by the node n_k to receive a data packet of L bits is given by

$$E^{Rx}_k = E_{\text{trans\_Rx}} = P_{\text{crx}} T_{\text{on}} \tag{7}$$

After transmitting or receiving 1-bit data, the RE of n_k can be given by

$$E^R_k = \begin{cases} E^i_k - E^{Tx}_k & \text{for } L\text{−bit transmission} \\ E^i_k - E^{Rx}_k & \text{for receiving } L\text{−bit} \end{cases} \tag{8}$$

In general, the energy consumed by the system per cycle is given by [12] the energy consumed by the radio transceivers, protocol processor, the efficiency losses in the battery, and DC–DC converter which regulates voltage for different components.

MBFA calculates the total energy consumed by the route during packet forwarding. For MBFA and total energy consumed for Z hops can be written as

$$E_T = \sum_{k=0}^{Z-1} [E^{Tx}_k + E^{Rx}_{k+1}] + \sum_{k=0}^{Z} [E_{\text{CPU}} + E_{\text{Bat}} + E_{\text{DC}} + E_{\text{Idle}}] \tag{9}$$

4 Numerical Results

Two network topologies of Grid and random for Varying network Traffic with different node densities 15, 30, 45, 60 over an area 1000 m^2 are configured on the QualNet Simulator using BFA and MBFA routing algorithms. For simulation, IEEE 802.11a/g standards are considered as shown in the Table 1. A Bit Error Rate (BER) reception model and 64-QAM modulation scheme with simulation time of 3000 s and Group Mobility, Random Mobility models are considered for mobility.

Table 1 OFDM simulation parameters for IEEE 802.11a/g

Parameter	Value
BW: channel bandwidth	20 MHz
N_{FFT}: Size of FFT	64
N_{SD}: Number of data subcarriers	48
N_{SP}: Number of pilot subcarriers	4
$N_{\mathrm{ST}}(= N_{\mathrm{SD}} + N_{\mathrm{SP}})$: Total number of subcarriers	52
$\Delta_F = \frac{F_S}{N_{\mathrm{FFT}}}$: Subcarrier frequency spacing	0.3125 MHz (=20 MHz/64)
$T_b = \frac{1}{\Delta_F}$: Useful symbol time	3.2 µs
T_g: Cyclic prefix (CP) time	0.8 µs
$\beta = \frac{T_g}{T_b}$: Cyclic prefix ration	¼
$T_s = T_b + T_g$: Symbol interval	4 µs
T_{Preamble}: PLCP preamble duration	16 µs $(T_{\mathrm{Short}} + T_{\mathrm{Long}})$

Table 2 Simulation parameters generic radio energy model

Parameter name	Symbol	Value (mW)
Transmit power	P_{Tx}	100
Receive power	P_{Rx}	130
Mixer power consumption	P_{mix}	30.3
Filter power consumption	$P_{filt} = P_{filr}$	2.5
Synthesizer power consumption	P_{syn}	50
LNA power consumption	P_{LNA}	20
DAC power consumption	P_{DAC}	15.4
ADC power consumption	P_{ADC}	14
IFA power consumption	P_{IFA}	3

The generic radio energy model [12] in QualNet Simulator is considered for energy calculation as shown in the Table 2. The various parameters used for simulation are 120 mAh battery initial capacity, 3.37 V battery voltage, 0.000002 change in node capacity as a threshold, 217–402 m radio range, 2.3 path loss coefficient (2-ray model), a data packet of 512 bytes, and 2.4 GHz radio frequency.

The residual battery capacity of BFA and MBFA using grid and random topologies with and without mobility is shown in the Table 3. Multiple sources and multiple destinations are considered with different network sizes with node densities of 5, 30, 45, and 60. The network with varying network traffic considered for the simulation. The total packets received verses number of nodes is shown in Fig. 2. The simulation results show that the number of packets received in MBFA is better compared to BFA. As the mobility of the node increases, the delay spread increases which results in the loss of orthogonality among the OFDM subcarriers and cause intercarrier interference (ICI) due to which the total number packets

Table 3 Residual battery capacity (mAh)

No. of nodes	Without mobility				With mobility			
	Grid topology		Random topology		Grid topology		Random topology	
	BFA	MBFA	BFA	MBFA	BFA	MBFA	BFA	MBFA
15	1567.78	1775.8	1567.59	1775.6	1567.25	1776.1	1568.07	1776.1
30	3150.15	3551.2	3135.7	3549.6	3150.43	3553.2	3135.48	3550.3
45	4388.1	4968.9	4702.56	5320.9	4388.31	4973.0	4701.87	5324.5
60	6685.06	7571.3	6268.88	7096.0	6684.7	7574.7	6268.41	7098.3

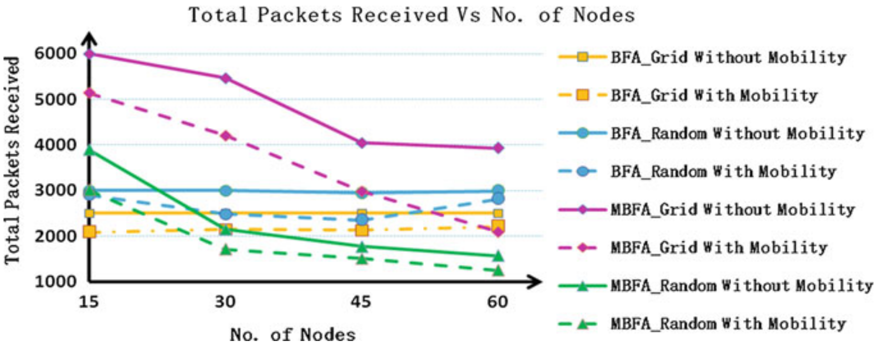

Fig. 2 Total packet received versus number of nodes with varying network traffic

received will be reduced. The performance of Grid topology is good when compared to random topology. In grid topology, the nodes are placed on exact, predefined points on a grid, and in the random deployment technique the randomness of the deployment is not in our control.

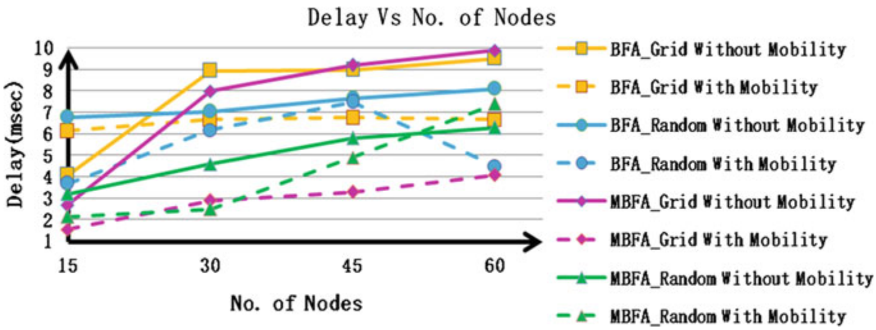

Fig. 3 Delay versus number of nodes with varying network traffic

The end-to-end delay verses number of nodes is shown in Fig. 3. As the size of the network increases, the traffic in the network increases which increases the average end-to-end delay due to multiple sources and destinations.

5 Conclusions

Mobile ad hoc networks require energy-efficient routing techniques to save battery capacity which improve the lifetime of the network. In this paper, energy-efficient modified Bellman–Ford algorithm is proposed. In modified Bellman–Ford algorithm residual energy is considered as a metric in additional to distance and hop count. All the nodes whose change in battery capacity is less than the threshold battery capacity are considered for routing. IEEE 802.11a/g OFDM standards using 64-QAM with generic radio energy model in QualNet Simulator is considered for energy calculation. In addition to the energy consumed by the radio transceiver circuit, the energy consumed by the processor, losses in the battery, and DC–DC converter are taken into consideration for energy calculation. Different scenarios of grid and random topologies using different network sizes 15, 30, 45, and 60 with multiple sources and destinations are considered for simulation. The impact of node deployment, mobility, and network size are considered for Bellman–Ford algorithm and modified Bellman–Ford algorithms. Simulation results shows that the performance of modified Bellman–Ford algorithms is better compared to Bellman–Ford algorithm and performance of grid topology is better when compared to random topology due to randomness of the deployment. Mobility of the nodes results increase in delay spread and the loss of orthogonality among the OFDM subcarriers which cause inter carrier interference hence number of packets received will be reduced. Hence, the performance of static network is better when compared to a mobile network. As the size of the network increases, the traffic in the network increase due to more number of multiple sources and multiple destinations. As the network size increases the average delay and jitter increases.

For future work, the performance of modified Bellman–Ford algorithm is improved by cooperative relays using a power saving mode will be studied.

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