MBA-OLSR: A Multipath Battery Aware Routing Protocol for MANETs

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Abstract— Recently, the proliferation of the smart mobile devices with embedded sensors, computing resources, and wireless technologies have enabled mobile ad hoc networks (MANETs) to play a key role for the emergence of the concept of “Smart City”. However, the mobile node’s battery has limited capacity and represents a constraint for MANETs. Constructing a power aware and efficient routes has received a great attention from researchers as a significant issue to maximize the network lifetime. In this context, this paper proposes a Multipath Battery Aware routing protocol namely: MBA-OLSR which is based on Multipath Optimized Link State Routing Protocol (MP-OLSR). To improve energy efficiency during routing, the MBA-OLSR considers the residual battery of the mobile node as a metric to find the initial cost of the multiple links. The proposed MBA-OLSR provides a major enhancement in node lifetime, and QoS metrics against variation in simulation time in different simulation models.

Keywords— MANET, MBA-OLSR, MP-OLSR, Routing Protocols, Power Efficient.

I. INTRODUCTION

The proliferation of the smart mobile devices with embedded sensors, computing resources, and wireless technologies, has presented a new ensemble mobile environment. These sensor-enabled smart mobile devices are ideal candidates to catalyze several useful services and applications in Smart City applications [1]. They also present Mobile ad hoc networks (MANETs) [2] as an essential component of the Smart City-infrastructure as well as wireless sensor networks (WSN) and wireless mesh networks (WMN) [3]. There is such a wide variety of MANETs applications, partially based on, for example, tactical networks, emergency services, commercial and civilian environments, home and enterprise networking, education, and coverage extension.

The MANETs represent complex distributed systems that comprise wireless mobile nodes that can freely and dynamically self-organize into arbitrary and temporary, “ad-hoc” network topologies, allowing people and devices to seamlessly internetwork in areas with no pre-existing communication infrastructure, e.g., disaster recovery environments [4]. The MANETs routing protocols are used to route the packets from the source node to the destination. These routing protocols should be efficient in terms of quality of service (QoS) metrics and energy consumption to guarantee the data transmission over the wireless medium [5]. The Internet Engineering Task Force (IETF) has developed four (4) routing protocols for MANET [6]: Ad hoc On-demand Vector: (i) (AODV), (ii) Dynamic Source Routing (DSR), (iii) Topology Dissemination Based on Reverse-Path Forwarding (TBRPF), and (iv) Optimized Link State Routing (OLSR) [7]. The efforts of the IETF are being made to standardize the OLSRv2 [8], a successor to OLSR, and Dynamic MANET On-demand (DYMO) which is currently known as AODVv2, a successor to both AODV and DSR routing protocol [6].

The limited battery capacity of mobile nodes represents a constraint for MANETs. Thus, the design of power efficient routes is a significant need to limit the power consumption, prolong the battery life and to improve the robustness of the system. The node power failure restricts the node’s ability to relay packets to others as an intermediate node rather than the device itself. Thus, routing a packet between source-destination pairs requires an adequate number of nodes between them to forward the packets.

The multipath routing protocols are proposed to address some routing issues for example: scalability, security, and transmissions instability. MultiPath-Optimized Link State Routing protocol (MP-OLSR) is proposed in [9] as a multipath extension to OLSRv2 [8]. In the MP-OLSR protocol, the Multipath Dijkstra Algorithm is proposed to obtain multiple paths from a source to a destination. In addition, route recovery and loop detection are implemented in MP-OLSR in order to improve QoS regarding OLSR. The algorithm utilized two cost functions for the link cost between nodes to generate node-disjoint or link-disjoint paths. However, the MP-OLSR used the number of hops as a metric to find the best path to the destination, and the cost of the links is initialized to one (1) as shown in Figure 1.

Figure 1. MP-OLSR multiple paths in initial state cost function
The costs of the links between two nodes are treated equally, i.e. the path with the least hop counts (shortest path) is considered as the best path. However, this measurement is not always correct because his choice can lead to a significant reduction of network performance when the network operates for long time or if there are some nodes in the network with low battery levels. In such situations, some batteries of the nodes will be exhausted when these nodes always chosen in the shortest path to the destination. In other words, the shortest path not always is the efficient path. Thus, the evaluation of links energy efficiency is a key factor to be considered.

In this paper, we propose an algorithm for route computation in the MultiPath-OLSR (MP-OLSR) [9]. Our enhanced protocol known as Multipath Battery Aware OLSR (MBA-OLSR). The enhanced protocol considers the residual battery level of the nodes during route computation. Then the MultiPath Dijkstra Algorithm can make use of the cost based on residual battery energy as the initial cost of the links between each pair of nodes to find the best path to a destination insted of number of hops that used in the original MP-OLSR. The simulation results show that our MBA-OLSR improve the energy consumption and it is more efficient than MP-OLSR in terms of energy consumption and QoS metrics.

The rest of this paper is organized as follows. In Section II, we present an overview on both versions of OLSR and MP-OLSR routing protocols. In Section III the related works are highlighted. followed by the proposed MBA-OLSR protocol in Section IV. The simulation models with the performance metrics in Section V. Then, Section VI presents the simulation results and discussion with comparison. Finally, the conclusion is drawn up in Section VII.

II. BACKGROUND

In this section, we provide an overview of the both versions of OLSR and its multipath extension and their functionalities.

A. OLSRv1 and OLSRv2 Overview

OLSR [7] is the currently most employed and leading proactive routing protocol in mobile ad hoc networks and the first version of OLSR (OLSRv1). It has been standardized as an experimental (RFC 3626) [7]. It works in a proactive manner, i.e., topology information is exchanged between the nodes on a periodic basis. The core optimization of OLSR is to minimize the control traffic by selecting a small number of nodes, known as Multi Point Relays (MPR) which is an improved flooding mechanism for topological information.

The second version of OLSR is OLSRv2 [8]. It is an update and successor to OLSRv1 as published in RFC3626. It holds the same basic mechanisms and algorithms of OLSRv1; however, OLSRv2 provides an even more flexible signaling framework and some simplification of the exchanged messages between nodes. It also accommodates both IPv4 and IPv6 addresses in a compact fashion. The OLSRv2 is developed for MANETs. Basically, it modifies the OLSRv1 by using and extending the following generalized building blocks: The MANET NeighborHood Discovery Protocol (NHDP) defined in [RFC6130] [10], The Generalized MANET Packet/Message Format [RFC5444] [11], The TLVs as specified in [RFC5497] [12] and, optionally, message jitter as specified in [RFC5148] [13], the OLSRv2 is in its final stage of standardization [14].

B. MP-OLSR Overview

This section discusses the concept and functionalities of the MP-OLSR [9]. It is a hybrid multipath routing protocol based on OLSRv2, which is proposed to improve QoS, load-balancing, and energy conservation. It takes advantage of the MPR mechanism to flood the network with control traffic information and includes a major modification of the Dijkstra algorithm as detailed in Algorithm 1. The MP-OLSR changes the OLSR proactive behaviour to on-demand route computation and becomes a source routing protocol with two cost functions to produce multiple disjoint or non-disjoint paths. The incremental functions Cost Function $F_p$ and Cost Function $F_c$: are used at each step to get a disjoint path between s and d. $F_c$ is used to increase the costs of the arcs that belong to the previous path $Pi$ (or the opposite arcs belonging to $i$). This will make future paths tend to use different arcs. $F_c$: is used to increase the costs of the arcs that lead to vertices of the previous path $Pi$.

Algorithm 1 : The MultiPath the Dijkstra algorithm:

Calculate N routes in G from s to d
MultiPathDijkstra(s, d, G, N)

$s = \text{SourceTree}_i = \text{Dijkstra}(G_i, s)$
$P_i = \text{GetPath}(\text{SourceTree}_i, d)$

for all arcs $e$ in $E$

If $e$ is in $P_i$, or $\text{Reverse}(e)$ is in $P_i$, then

else if the vertex $\text{Head}(e)$ is in $P_i$, then

else

end if

end for

$G_{i+1} = (V, E, C_{i+1})$

end for

return ($P_1, P_2, ..., P_N$)

To maintain several paths for the same pair (source, destination), there are two main phases: (i) Topology sensing, and (ii) Route computation. The topology sensing phase includes link sensing, neighbor detection and topology discovery. The nodes obtain a partial topology map just like in OLSR based on the periodic exchange of HELLO and TC messages. However, MP-OLSR nodes do not construct routing tables. Throughout the route computation phase, nodes calculate multiple paths (one is a primary path and the others are secondary paths) and to reach any other node in the network following an on-demand scheme and based on topology sensing information. Furthermore, the MP-OLSR

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has two auxiliary phases: Route recovery and Loop detection to improve its performance. Also, it is compatible with standardized OLSR by using the IP source routing.

III. RELATED WORKS

A number of studies on power-aware routing that considers the available energy of the nodes to take the routing decisions. The authors in [15] proposed OLSRE, an enhanced version energy efficient routing based on OLSR. In OLSRE, the energy consumption is taken into account during packet routing by calculating the cost of packet transmission. However, this protocol has a high overhead and it does not consider a node’s residual energy. Another approach of energy efficient OLSR-based routing protocol is OLSR_EA [16] with the auto-regressive integrated moving average time series method to measure and predict per-interval energy consumption. The authors developed a composite energy cost, by considering residual energy and the consumed transmission power of each node, and used this compound energy index as the energy routing metric. However, in OLSR_EA, there is a higher chance of collision if a relay node has a longer transmission range than surrounded nodes, therefore, it is not preferred in large networks.

EEOLSR [17] is an enhanced version of OLSR for extending the network lifetime without loss of performance. The authors modified the multipoint relay (MPRs) selection mechanism of OLSR protocol based on EA-Willingness concept mechanisms by considering the energy state of the node during MPR selection. However, the EEOLSR has not considered the residual battery for route computation. In [18] the authors proposed OLSRM protocol based on the standardized OLSR. They have tried to make it energy efficient by proposing efficient neighbour selection based on node's residual energy and drain rate. They have considered the multipath and source routing concept for route selection. Although several works in the literature have been proposed to optimize the energy consumption of OLSR, however, all of them based on the standardized first version of OLSR (OLSRv1). To the best of our knowledge, none of the researches in the literature considers the energy efficiency of OLSRv2 [8], the successor to OLSRv1; or its multipath extension MP-OLSR [9].

IV. THE PROPOSED MBA-OLSR

As we mentioned earlier, the MP-OLSR applies the number of hops as link cost metric for transmitting the data. Initially, it sets the cost for all links to "1" which can either lead the congestion on a specific path, or rise in the energy expenditure of particular intermediate nodes. For the proposed MBA-OLSR, the same MultiPath Dijkstra Algorithm as shown in Algorithm 1 [9] was utilized. However, the initial link cost of each link is calculated based on the residual battery of both nodes for each link.

Since the topology information in OLSR and MP-OLSR is exploited by exchanging HELLO and TC messages, we need to modify these messages for MBA-OLSR and attach the residual energy information of the node to them. The

Type-Length-Value (TLV) mechanism of OLSRv2 [12] allows to add an additional TLV for the residual battery information. These modifications make other nodes in the network aware of the residual battery information in the local node. As shown in Figure 2, a TLV_Residual Battery is added to the HELLO and TC messages and broadcasted to the whole network. Upon the reception of HELLO or TC messages, the residual battery value is extracted from the TLV_Residual Battery. An inversely weight function is employed to define the link cost to the next hop nodes based on their residual batteries energy.

\[
\text{Residual Battery ratio} = \frac{\text{Node Residual Battery}}{\text{MAX Battery Capacity}}
\]
\[
\text{Link Cost} = k \times (1/ \text{Residual Battery ratio})
\]  
where:

- \( k \): is the weight factor to optimize the impact of different residual battery on the link cost. This parameter is selected to investigate the behavior of the protocol different weight factor values.

If multiple paths are available, initially, the cost of all links is equal to link cost obtained from equation (2). The next hop nodes are selected based on their weights which is updated based on the link cost to them. The nodes with the highest level of residual battery will be connected by the links with minimum cost and construct the best route to the destination. The multipath computation process is explained in the flow chart in Figure 3.

V. SIMULATION MODEL

A. Simulation Tools

EXata 3.1 Simulator [19] is employed to evaluate the performance of MBA-OLSR. It is used to conduct extensive simulations to evaluate the energy efficiency of the MBA-OLSR as well as compare it with the MP-OLSR routing protocol in different scenarios. The EXata communication simulation platform is a network emulator that is integrated into the well-known QualNet network simulator, which is widely used in academic research and industry [9]. The EXata simulator platform offers a high level of reliability and scalability simulations for wireless communication.

B. Network Model

Basically, the MANET network can be modelled using a graph \( G (V, E) \), where \( V \) is the set of nodes representing the mobile devices and \( E \) is a set of arcs; each arc models the intersection of two devices’ communications range [20]. Each node \( v \in V \) can directly communicate with a set of neighboring devices within its communication range; otherwise, it has to use a routing protocol to transmit packets to remote devices, that are not adjacent neighbors. One of the possible paths in the graph \( G (V, E) \) can be used to transmit the packets from the node \( v \) to the destination node. Due to the node’s mobility, the network topology frequently changes. Thus, the cardinality of nodes in set \( V \) remains the same throughout the period whereas the cardinality of edges in \( E \) keeps changing. As the number of nodes in set \( V \) increases, the average hop length of \( E \) also increases, which affects the routing protocol performance.

C. Energy Model

In multi-hop wireless networks, the energy consumption is an important issue. Since nodes are a battery-operated, the battery energy is limited and a node can only transmit a restricted number of bits. The maximum number of bits that can be transmitted is defined by the total battery energy divided by the required energy per bit. There are four states for the mobile node in a wireless network: namely: Transmit Receive, Idle and Sleep. Each state consumes a particular amount of energy. In our simulation model, we used a Generic Radio Energy Model which is derived to estimate the consumed energy in each state. Therefore, the total energy consumption for a node to transmit and receive a packet can be calculated as follow:

\[
E_{\text{total}} = E_{\text{trans}} + E_{\text{rec}} + E_{\text{idle}} + E_{\text{sp}}
\]

where:

\[
E_{\text{trans}} = P_{\text{transmit}} \times t_{\text{trans}}
\]

\[
E_{\text{rec}} = P_{\text{receive}} \times t_{\text{rec}}
\]

\[
E_{\text{idle}} = P_{\text{idle}} \times t_{\text{idle}}
\]

\[
E_{\text{sp}} = P_{\text{sp}} \times t_{\text{sp}}
\]

and \( t_{\text{trans}}, t_{\text{rec}}, t_{\text{idle}}, \) and \( t_{\text{sp}} \) are the duration of time for each state. We set the energy parameters in our simulation scenarios as listed in Table I, based on Reference [17].

D. Simulation Environment and Parameters

The network simulation topology is displayed in Figure 4. The scenarios terrain of 1000 m by 1000 m with a spread out 50 mobile nodes placed with randomly distributed in 5 groups (10 nodes each) based on maximum speed and pause time of their Waypoint mobility model to reflect a real deployment scenario for mobile nodes with different speeds and pause times as shown in Table I.

In the considered scenario, the simulation time was changed from 100 to 500 Sec and the Constant Bit Rate (CBR) flows are randomly selected for 10 source-destination pairs and came 10 Sec after the simulation started. This is to give plenty of time for exchanging routing messages. The cbr with interval of 0.05 Sec and size of 512 bytes. The used radio type in our simulations is 802.11b Radio with Omni directional antenna model and 11 Mbps data rate. The wireless channel frequency was set to 2.4 GHz and the radio transmission range was about 270 m as a result of the selected Wi-Fi parameters setting. All nodes were provided with a linear battery model with full battery capacity of 10 mAh. All simulation scenarios were repeated 5 times with different randomly selected seeds to get different experiments, and the results were averaged over all experiments. The parameters that we used in our simulation were used in similar previous studies.
TABLE I. SIMULATION PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing Protocol</td>
<td>MBA-OLSR and MP-OLSR</td>
</tr>
<tr>
<td>Simulation area</td>
<td>1000m x 1000m</td>
</tr>
<tr>
<td>Mobility</td>
<td>Random Waypoint</td>
</tr>
<tr>
<td>GROUP 1</td>
<td>[0-1] mps, Pause: 30 Sec</td>
</tr>
<tr>
<td>GROUP 2</td>
<td>[0-5] mps, Pause: 5 Sec</td>
</tr>
<tr>
<td>GROUP 3</td>
<td>[0-15] mps, Pause: 15 Sec</td>
</tr>
<tr>
<td>GROUP 4</td>
<td>[0-20] mps, Pause: 20 Sec</td>
</tr>
<tr>
<td>GROUP 5</td>
<td>[0-25] mps, Pause: 25 Sec</td>
</tr>
<tr>
<td>Energy Model</td>
<td>Generic:</td>
</tr>
<tr>
<td>( P_{\text{transmit}} )</td>
<td>1400 mW</td>
</tr>
<tr>
<td>( P_{\text{receive}} )</td>
<td>1000 mW</td>
</tr>
<tr>
<td>( P_{\text{idle}} )</td>
<td>0.0 mW</td>
</tr>
<tr>
<td>( P_{\text{sleep}} )</td>
<td>0.0 mW</td>
</tr>
</tbody>
</table>

E. Performance Evaluation Metrics

The main aim of this work is to evaluate the energy efficiency and QoS metric of our improved MBA-OLSR routing protocol. For this purpose, the following evaluation metrics were considered:

- **Residual Battery of the node**: The metric gives the amount of residual battery for each node at the end of simulation time. Also, this metric can show the dead nodes at the end of the simulation.
- **Energy consumption**: The metric gives the average of energy consumed by each node for data transmitting and receiving.
- **Energy Cost per Packet**: This metric gives the ratio between the total consumed energy over the number of successfully received packets at the destinations.
- **Packet delivery ratio (PDR)**: The ratio of the data packets successfully received at the destination.
- **Average End-To-End Delay**: It refers to the average time duration over all surviving data packets that are transmitted from the source to the destination.

VI. MBA-OLSR PERFORMANCE EVALUATION

In this section, the performance evaluation for the enhanced MBA-OLSR is carried out with a comparative analysis with MP-OLSR based on the selected energy efficiency and QoS metrics. In the deployed simulation scenario, we have selected simulation time to evaluate the performances of our protocol because it is one of the most important parameters involves in the nodes and network lifetime.

Figure 5 (a) and Figure 5 (b) present the impact of the simulation time on the residual battery metric for the MBA-OLSR and the MP-OLSR respectively. The results show that the performance of MBA-OLSR is much better since it significantly save the battery energy and all the nodes keep running in all sub scenarios until the end of the simulations.

On the other hand, the new modification to the proposed MBA-OLSR protocol to improve its energy efficiency doesn’t degrade other QoS metrics and it outperforms the MP-OLSR in terms of packet delivery ratio and average end-to-end delay as it is shown in Figure 8 (a) and (b) respectively. In overall, the MBA-OLSR increases the PDR by 60 % and decreases the average end-to-end delay to 0.018 [Sec] which is 98% lower compared to the MP-OLSR. This is because some mobile nodes in the MP-OLSR scheme are utilized more than other nodes, thus, their batteries are exhausted and caused degradation in the QoS metrics as the run time increases. However, in our MBA-OLSR there is an appropriate energy consumption balancing among the mobile nodes and performs better in all sub-scenarios.
VII. CONCLUSIONS

This study evaluated the energy efficiency of our protocol MBA-OLSR and compared its performance metrics with the MP-OLSR based on particular scenarios. The proposed MBA-OLSR showed a superiority with a significant reduction in energy consumption besides achieving highest packet delivery ratio and lowest end-to-end delay in all sub-scenarios. However, we need more evaluation of our protocol, therefore, in the future work we will perform an extensive evaluation of our proposed protocol in different simulation scenarios, also we will investigate the impact of network size and traffic on the performance of the proposed protocol.

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