A Cluster-Based Model for QoS-OLSR Protocol

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***Abstract*—The QOLSR is a multimedia protocol that was designed on top of the Optimized Link State Routing (OLSR) protocol. It considers the Quality of Service (QoS) of the nodes during the selection of the Multi-Point Relay (MPRs) nodes. One of the drawbacks of this protocol is the network lifetime, where nodes with high bandwidth but limited energy can be selected to serve as MPRs, which drain nodes' residual energy and shorten the network lifetime. In this paper, we consider the tradeoff between prolonging the ad hoc network lifetime and QoS assurance based on QOLSR routing protocol. This can be achieved by (1) reducing the number of Multi-Point Relay (MPR) nodes without sacrificing the QoS and (2) considering the residual energy level, connectivity index, and bandwidth of these relay nodes. These objectives can be reached by deploying the clustering concept to QOLSR. Therefore, we propose a novel clustering algorithm and a relay node selection based on different combinations of metrics, such as connectivity, residual energy, and bandwidth. Four cluster-based models are derived. Simulation results show that the novel cluster-based QoS-OLSR model, based on energy and bandwidth metrics, can efficiently prolong the network lifetime, ensure QoS and decrease delay.**

***Index Terms*—Quality of Service (QoS), Head Election, MPR Selection and Ad Hoc Networks.**

I. INTRODUCTION

The *Optimized Link State Routing* (OLSR) protocol [6] is a proactive routing protocol designed for mobile ad hoc networks. It relies on a set of designated nodes to broadcast the network topology information and to forward traffic flows towards their destination. These nodes are known as the *MultiPoint Relay* (MPR) nodes. Based on the OLSR protocol, the Quality of Service (QoS) OLSR protocol, known as QOLSR [2], was proposed in literature to consider the nodes' available bandwidth during the selection of MPR nodes and routing paths. It was designed to handle multimedia applications over ad hoc networks. The bandwidth and delay metrics that are needed to ensure QoS are used during the MPR selection. The QOLSR protocol has a main limitation that can ultimately jeopardize the ultimate goal of the protocol, where the network lifetime can be shorter due to the selection of large number of MPR nodes. This is due to the fact that, in QOLSR protocol, every node selects independently its own set of MPR nodes. Such a problem can affect nodes' available bandwidth and increase the probability of channel collision, especially in dense networks [9]. Finally, QOLSR can select nodes with low residual energy levels.

To address the above limitation, we propose a solution based on clustering, where nodes can cooperatively select a set of heads to serve as MPRs. Once the head nodes are elected and consequently clusters are formed, the elected nodes will cooperatively select the set of MPRs that can connect these clusters. In literature, clustering in OLSR was considered as a solution for prolonging the network lifetime, by reducing the percentage of MPRs. Therefore, clusters are formed and then MPRs are selected according to their private information such as residual energy or connectivity index (valency) [11], [12]. Note that all the proposed models assume the presence of clustering models that can cluster the network and then the MPRs are selected. While in our model the heads are selected cooperatively and then the heads will select the MPRs that can connect the heads with each others (1-hop, 2-hop and 3-hop away).

Based on the clustering concept, we propose a solution that has four different clustering models based on three metrics: bandwidth, connectivity index and residual energy. To the best of our knowledge, there has not been any work done that considers the tradeoff, for QOLSR, between network lifetime and QoS based on clustering. Simulation results are conducted to evaluate the performance of the proposed models compared with the classical one. In summary, our contribution, is a novel cluster-based QoS-OLSR approach that is able to:

- Prolong the network lifetime by reducing the percentage of MPR nodes which eventually reduces the traffic overhead and channel collisions.
- Cooperatively select the set of MPRs based on nodes' QoS metric.

The rest of this paper is organized as follows. Section II reviews the related work. Section III presents the clustering based QOLSR including the head and MPR selection. Section IV presents empirical results. Finally, Section V concludes the paper.

II. RELATED WORK

This section briefly reviews the prior work of QOLSR, the connectivity-based and energy-based clustering approaches for

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OLSR and the use of mechanism design theory for ad hoc networks.

A. QOLSR

OLSR [6] is a classical link state protocol that has been tailored for the requirements of ad hoc networks. The Multi-Point Relay (MPR) nodes are the key concept of this protocol where they are selected by all the nodes to broadcast the network topology information with their Topology Control (TC) messages and to forward traffic flows towards their destination. This optimization technique reduces substantially the overhead of the control messages. Hence, the protocol is particularly suitable for large and dense networks. Unfortunately, OLSR cannot guarantee or ensure QoS since it was not designed for multimedia purposes. To cope with this limitation, QOLSR [2] routing protocol was developed based on OLSR where QoS has been considered. This raises the need for new metrics such as bandwidth and delay. Thus, the aim is to find a source-destination routes, but the optimal ones that satisfies the end-to-end QoS requirements. The selection of MPRs are based on the QoS measurements that allow QOLSR to find optimal paths. Multiple-metric routing criteria were considered in order to improve the QoS of the route. The QOLSR has two main limitations. MPRs are selected based on nodes bandwidth without considering nodes energy level and connectivity which can shorten the network lifetime.

B. Connectivity-Based and Energy-Based Clustering Models

The HOLSR protocol [12] relies on a hierarchy of nodes: nodes with higher communication capabilities and regular nodes. The former nodes act as an interconnected mesh of cluster heads that can be seen as mobile access points. The latter nodes are grouped into clusters. Each regular node finds which cluster head to be attached to. To reach any remote destination, the traffic is routed towards the local cluster head and forwarded to the appropriate remote cluster head.

The OLSR Tree protocol [1] uses a different approach. Each node selects as its parent its adjacent node with the maximum number of direct neighbors. This partitions the network into a set of overlapping trees – a leaf node can belong to more than one tree. Each tree forms a cluster and its root is the local cluster head. The cluster heads use an extended version of OLSR and determine a set of super MPR nodes to interconnect them. Each cluster/tree acts as a unique super node for this extended OLSR protocol.

Finally, a recent solution proposes to address the scalability problems of very large scale ad hoc networks [4]. It is fully independent of the clustering protocol used. OLSR and its classical messages are limited to the local clusters. To interconnect these clusters, super TC messages are broadcast by the cluster heads. Based on these messages, any source knows the next hop node towards any destination. This step is simpler than the extended OLSR used in the previous solution.

In order to reduce the energy consumption and increase the network lifetime, different approaches propose to use the node residual energy as a metric for the routing protocol. The selection can rely on a simple metric based on the residual energy levels of the nodes or on a more complex weighted metric based on the residual energy levels of the nodes and their connectivity [8]. The choice of this criterion depends on the physical model of energy consumption of the nodes. Some solutions simply assign very high costs to links coming out of nodes with very low residual energy levels and use the Dijkstra's algorithm to compute the lowest total cost paths (e.g., [3] and [7]). However, other criteria can be defined. A local criterion could be used and a path minimizing the maximum energy used by any single node of the path should be preferred [10]. Note that all the presented approaches are based on clustering then heads are selected and thus clusters are formed. While, our model is based on head selection and then clusters are formed. Clusters are connected through the selection of the best MPRs. In our previous work [5], we have addressed the problem of lifetime and security for OLSR and not for QOLSR. In this work, we addressed the impact of clustering on QoS and how this can affect multimedia applications over ad hoc networks.

III. Cluster-Based QoS-OLSR Model

In this section, we present the Quality of Service metric function of our models that are bandwidth, connectivity index, and residual energy. Implementing these concepts will help us to prolong network lifetime without sacrificing QoS. Our solution can be summarized as follows. First, the cluster head election algorithm elects a set of optimal cluster heads. Second, the elected cluster heads will select the set of optimal MPR nodes that can lead to a connected network.

A. The Quality of Service Metric Models

To have a better performance and quality of service, we introduce the cluster-based QoS-OLSR approach. In the classical QOLSR, each node chooses its own MPR according to maximum bandwidth and minimum delay. In this paper, the classical QOLSR will be known as "without clustering" under different models according to the QoS metric used. The models are presented in Table I. Note that throughout this paper the QOLSR will be called as "without clustering BOLSR".

Our proposed model is known as "with clustering" and it has four different models according to the different QoS metrics. In the new approach, the network is divided into clusters by selecting the set of optimal head clusters that can serve as MPR node. Heads are elected according to the highest QoS Metric value. After the cluster head election is done, each head will elect the MPR nodes according to nodes' QoS Metric function that are based on the QoS parameters. By introducing clustering to the classical QOLSR, we are distributing the energy consumption and thus increasing the network lifetime. In Table I, we define the Quality of Service Metric function of our four models with the new metrics and the notations used.

B. The Cluster Head Election

To elect the set of optimal cluster heads and divide the network into clusters, an election algorithm is modeled. Each

TABLE I
QUALITY OF SERVICE METRIC

Notations and Quality of Service Metric Function
Let i be a node in the network. Let define:
QoS(i) = Quality of Service Metric of a node
BW(i) = Available bandwidth of i
N(i) = Neighbors of i
RE(i) = Residual energy of i
Bandwidth Model (B-OLSR)
QoS(i) = $BW(i)$;
Proportional Bandwidth Model (Proportional B-OLSR)
QoS(i) = $\frac{BW(i)}{N(i)}$;
Bandwidth and Energy Model (BE-OLSR)
QoS(i) = $BW(i) \times RE(i)$;
Proportional Bandwidth & Energy Model (Prop. BE-OLSR)
QoS(i) = $\frac{BW(i)}{N(i)} \times RE(i)$

node votes for its neighbor which has the maximal Quality of Service Metric value. A node can also vote for itself, if it has the maximal local QoS Metric value. This solution gives a one-hop clustering model, i.e. each node is one-hop away from its elected cluster head. Once the election algorithm is done,

Cluster Head Election Algorithm
Let i be a node in the network.
Let $k \in N_1(i) \cup \{i\}$ be s.t.
$QoS(k) = \max\{QoS(j) \vert j \in N_1(i) \cup \{i\}\}$.
The node i votes for k.
$MPRSet(i) = \{k\}$.

the elected cluster heads would act as MPR nodes for their electors. Some modifications have to be done. The first one is to add a flag indicating that a node has been designated as a cluster head. The second one is to add a flag that a neighbor has been elected as a cluster head. Finally, for each of its neighbors, a node indicates for which node its given neighbor has voted for. The results of the election have to be propagated to the neighbors before they can update their local information.

C. The MPR Nodes Selection

Once the cluster heads have been designated, they are responsible to select a set of optimal MPR nodes. This set of nodes interconnects the clusters into a connected graph, if one exists. Note that the 1-hop cluster heads can be directly

MPR - Part I: Computing the neighbor clusters
Let k be any elected cluster head.
the 1-hop cluster heads as
$CH_1(k) = \{i \in N_1(k) \vert i \text{ has its CH flag set}\}$.
the 2-hop cluster heads as
$CH_2(k) = \{i \in N_2(k) \vert i \text{ has its CH flag set}\}$.
the 3-hop cluster heads as
$CH_3(k) = \{j \vert (\exists i \in N_2(k))[i \text{ voted for } j]\} \setminus N_{1,2}(k)$.
the set of cluster heads to be covered as
$CH(k) = CH_3(k) \cup$
$CH_2(k) \setminus \{j \vert (\exists i \in CH_1(k))[j \in N_1(i)]\}$.

reached and therefore there is no need to select MPRs in between. Moreover, the 2-hop cluster heads connected to 1-hop cluster heads do not require to select any MPR in between. Thus, the challenge is to cover the 3-hop cluster heads reliably. In MPR-Part II, the MPR nodes are computed to cover the 2-hop cluster heads.

MPR - Part II: MPR nodes for the nodes in $CH_2(k)$
Let k be any elected cluster head.
While $CH(k) \neq \emptyset$
Find $l \in CH(k) \cap CH_2(k)$ s.t.
The path (k, x, l) maximizes $QoS(x)$ among all paths connecting k to any other uncovered node.
$MPRSet(k) = MPRSet(k) \cup \{x\}$.
Remove from $QoS(k)$ all the nodes in $CH_2(k)$ reachable from x.

Finally, the 3-hop cluster heads are selected in MPR-Part III. In such a case, two MPR nodes are required to reach any 3-hop cluster head.

MPR - Part III: MPR nodes for the nodes in $CH_3(k)$
Let k be any elected cluster head.
While $QoS(k) \cap CH_3(k) \neq \emptyset$
Find $l \in QoS(k) \cap CH_3(k)$ s.t.
The path (k, x, y, l) maximizes $min(QoS(x), QoS(y))$ among all paths connecting k to any other uncovered node.
If there are two such paths, take the first one in the lexicographic order.
$MPRSet(k) = MPRSet(k) \cup \{x\}$.
Remove from $CH(k)$ all the nodes in $CH_3(k)$ reachable from x.

The correctness of this part has to be proven formally. If the cluster head k selects the MPR node x, the cluster head l has to select the MPR node y to assure that k and l are connected.

It is important to mention that the proposed model is a competitive model. Thus, it is necessary that each cluster head has more than one choice to connect to any of its neighbor cluster heads – either in Part II or in Part III of the MPR selection algorithm.

D. Illustrative Example

To illustrate the cluster head election and the MPR selection, Figure 1 shows a network with twenty nodes and Table II gives the Quality of Service Metric value of each node using the Proportional BE-OLSR Model (refer to Table I). To find the Quality of Service metric of each node in the network, the residual energy which is a random value between 500 and 550 (refer to Table II) is divided by connectivity index and multiplied by bandwidth. After receiving the Hello messages from its neighbors, a node votes for its neighbor with the maximal Quality of Service metric value. Using the Cluster Head Election Algorithm, nodes: 3, 4, 5, and 15 are elected as head clusters (MPRs).

TABLE II
THE QUALITY OF SERVICE METRIC USING THE PROPORTIONAL BE-OLSR MODEL

Node	$n1$	$n2$	$n3$	$n4$	$n5$	$n6$	$n7$	$n8$	$n9$	$n10$
QoS Metric	370.8	297.3	500.2	479.4	516.7	338.7	231.1	220.4	490.6	246.4
Node	$n11$	$n12$	$n13$	$n14$	$n15$	$n16$	$n17$	$n18$	$n19$	$n20$
QoS Metric	250.6	193.1	127.2	159.9	600.9	109.9	101.5	495.3	400.5	550.7

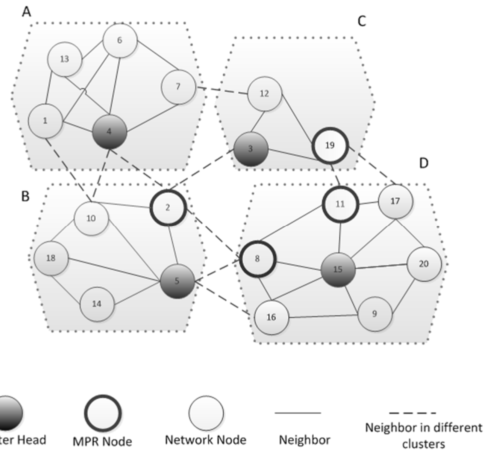

Fig. 1. Ad hoc Network example

Once the cluster heads are elected, they in turn select the MPR nodes that connect all heads together. We will consider node 15 in cluster D to illustrate our example. First, is to find the neighbor cluster heads for node 15. Referring to MPR-Part I, we need to find the $1-hop$ cluster head, $CH1$, the $2-hop$ cluster head, $CH2$, and the $3-hop$ cluster head, CH3. So, $CH1(15)=\phi$ since there is no $1-hop$ cluster head connected to node 15. $CH2(15) = 5$ since node 5 is a $2-hop$ cluster head to node 15, and similarly for $CH3(15)$=3 and CH3(15)=4.

The second step is to find the optimal path that will connect the 2-hop cluster heads that are node 15 and node 5. Node 8 and node 16 are common neighbors for these 2 head nodes, but according to MPR-Part II Algorithm, node 8 is chosen as the MPR node since it has a better QoS metric value than node 16. Now, we need to find the optimal path for the 3-hop cluster heads referring to MPR-Part III. There are two choices to connect head node 15 with head node 3, either through {node 11, node 19} or {node 17, node 19} or {node 8, node 2}. Head node 15 chooses the path {node 11, node 19} which has the maximal QoS metric value. However, head node 15 would select only node 11 as an MPR node and, by symmetry, head node 3 would select node 19 as an MPR node. Similarly, the optimal path with {nodes 8, node 2} to reach cluster head node 4 is found.

IV. Simulation results

Matlab-8.0 has been used to simulate with clustering and without clustering QOLSR to compare between the novel cluster-based QOLSR and the classical one (without clustering). The simulation is divided into four subsections. The first subsection shows the percentage of selected MPR nodes in the two scenarios: with clustering and without clustering models. The second part presents the percentage of alive nodes. The third subsection shows the path lengths that represent delay in the network. Finally, the bandwidth average difference for the models is presented to show the quality of service in the network. The simulation parameters are summarized in Table III.

TABLE III
SIMULATION PARAMETERS

Parameter	Value
Simulation area	500×500 m
Number of nodes	Between 30 and 70
Transmission range	125 m
Residual energy	Random value in [500..550] Joules
Packet Size	1 kb
Energy Per Packet	0.0368 J
Idle Time	Random value in [0..1]
Link Bandwidth	2Mbps
Available Bandwidth	$Idle\ Time \times Link\ Bandwidth$

A. Percentage of MPR nodes

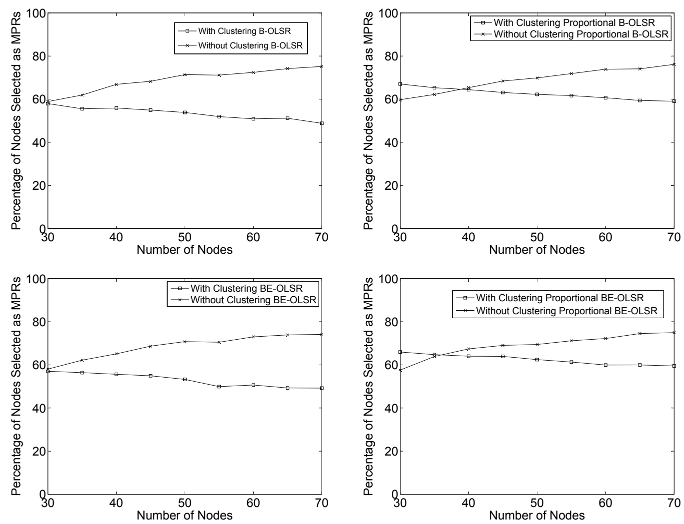

Fig. 2. Percentage of MPR Nodes: (a) B-OLSR (b) Proportional B-OLSR (c) BE-OLSR (d) Proportional BE-OLSR

In Fig 2, the cluster-based models significantly reduce the number of selected MPR nodes. These relay nodes include the cluster heads which act as specialized MPR nodes. This result is not surprising, since the regular MPR nodes are selected by a limited number of specialized nodes. Thus, the clustering approaches should reduce the congestion due to the TC messages and should be more suitable for dense networks. Comparing the four models, obviously in Fig 2, the “with clustering” BE-OLSR model has the minimum percentage of MPR nodes, since these nodes are selected according to the two parameters that are bandwidth and energy without being proportional to the number of neighbor nodes.

B. Network Lifetime

The energy consumption at node i is computed using the following parameters:

- $BW(i)$: Available bandwidth at node i.
- $RE(i)$: Residual energy of node i.
- $EN(i)$: Energy consumed by node i.
- Packet size.
- Energy per Packet.

In Fig 3, we show the percentage of alive nodes and how the energy drain for a 70 node network for all the models. The

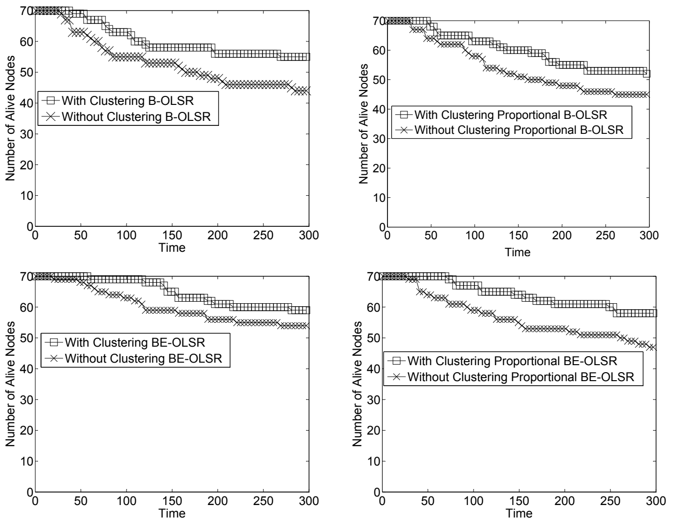

Fig. 3. Percentage of of alive nodes over time: (a) B-OLSR (b) Proportional B-OLSR (c) BE-OLSR (d) Proportional BE-OLSR

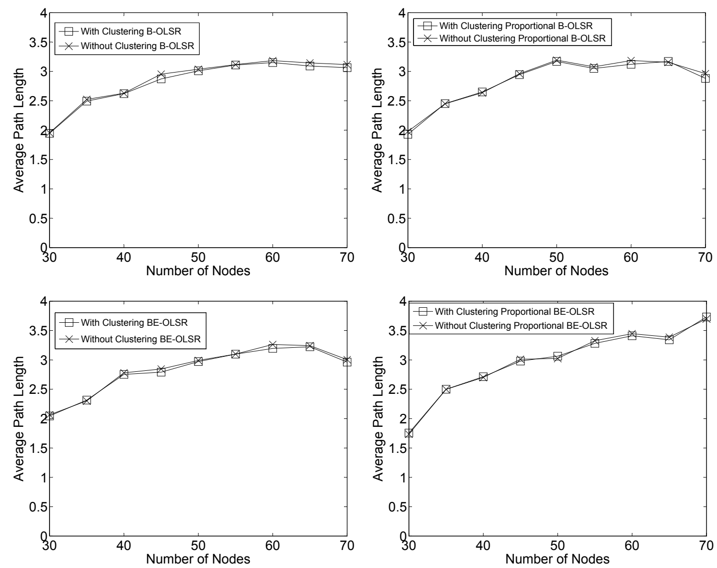

Fig. 4. Average Path Length with and without Clustering: (a) B-OLSR (b) Proportional B-OLSR (c) BE-OLSR (d) Proportional BE-OLSR

Energy Consumption (EN) is calculated using Equation 1. This will be done by finding the total number of packets the node i will transfer. This value is obtained by dividing the available bandwidth at node i by the mean packet size 1kb. Then, we have to multiply the total number of packets transferred by the energy per packet which is $0.0368J$ according to the simulation parameters table (refer to equation 1). The residual energy is decreased by the value of Energy consumption. (refer to equation 2)

$$EN(i) = (BW(i) \ / \ Packet\ size) \times \ Energy\ per\ Packet\ J \quad (1)$$

$$New\ RE(i) = RE(i) \ - \ EN(i)\ J \quad (2)$$

As expected, the clustered models in Fig 3 prolong the network lifetime compared to the without clustering models because we have less number of selected MPRs. It is significant that the with clustering proportional B-OLSR (see Fig 3,a) has the worst network life time among all clustered models, whereas, with clustering BE-OLSR shows the best results overtime compared to others. The models that depend on the residual energy prolong the network lifetime because the MPR nodes are chosen based on the residual energy of nodes. Also, the concept of clustering helped to reduce the energy consumption by selecting a set of specialized nodes.

C. End-to-End Average Delay in the Network

Another aspect to consider, in this analysis, is the end-to-end delay in the network. Fig. 4 represents the source-destination path length of the four different models “with clustering” and “without clustering”. The path length is presented by the average number of hops between source and destination. The path with the best Quality of Service metric is selected as the source-destination optimal path. In each figure, we show a comparison of the average path length for both models.The “with Clustering” and “without Clustering” Models showed similar results. Thus, to differentiate between the performances of the models, another criterion should be used. According to the results of the simulation, the BE-OLSR model with clustering gives better performance for the network lifetime and should be preferred over other cluster-based models.

D. The Bandwidth Average Difference

TABLE IV
BANDWIDTH AVERAGE DIFFERENCE

Models	Transmission Ranges		
	100	150	200
without clustering B-OLSR	0%	0%	0%
with clustering B-OLSR	0%	0%	0%
without clustering Prop. B-OLSR	10.55%	3.08%	4.9%
with clustering Prop. B-OLSR	10.6%	4.22%	2.59%
without clustering BE-OLSR	0.04%	0.15%	0.02%
with clustering BE-OLSR	0.09%	0.19%	0.09%
without clustering Prop. BE-OLSR	9.17%	5.88%	4.89%
with clustering Prop. BE-OLSR	9.24%	6.2%	3.42%

The bandwidth average difference is one of the aspects that we can consider in our models. It is the percentage average of the difference between the optimal bandwidth and the bandwidth currently available in the network. As the percentage decrease, the quality of service in the network improves. Table IV represents the percentage average difference for a 70 nodes network for the two scenarios: without clustering and with clustering. According to this table, the with clustering B-OLSR and without clustering B-OLSR have zero average difference since the optimal path is chosen according to the optimal bandwidth path. Other clustered models showed slightly more percentage average difference, especially the with Clustering BE-OLSR which is more by less than 0.1% , but it have better network lifetime and delay. Thus, it should be preferred over the B-OLSR. Choosing the best model regarding the percentage average difference, depends on the application. If the application is related to multimedia services that are error tolerated and delay not tolerated, the percentage average difference loses its importance compared to delay. Whereas in data services applications, errors are not acceptable so percentage average difference should be considered.

In Summary, based on the results in the above subsections, we are able to show that the novel cluster-based approaches are able to prolong network lifetime by selecting less number of MPRs, thus decreasing traffic overhead, delay, channel collision, and increasing cooperation in the network. On the other hand, comparing the clustered models with each others, we conclude that the energy is an essential metric that must be considered while selecting the MPRs. The cluster-based BE-OLSR model showed a marginal impact on average difference, whereas a large impact on the network lifetime. Therefore, the cluster-based approach must be preferred over the classical one taking into consideration nodes' energy.

V. Conclusion

The multimedia QOLSR protocol was proposed to handle multimedia applications over ad hoc networks. The MPRs are selected based on nodes bandwidth and delay without considering nodes' residual energy which can affect network lifetime. As a solution, we proposed different models based on the clustering concept with different QoS metric. Such models will reduce the channel collision and increase the throughput. The head and MPRs selection algorithms are presented. Moreover, a comparison between the "without clustering" and "with clustering" models was presented. The comparison addressed the percentage of MPR nodes, percentage of alive nodes in the network, the path length which reflects the delay, and quality of service. Simulation results showed that the "with clustering" models, in general, lead to a better results compared to the classical QOLSR (without clustering). Moreover, the "with clustering" BE-OLSR was able to consider the tradeoff between network lifetime, delay and QoS. The model shows much better results in network lifetime and path length and very close result in terms of available bandwidth with average difference between 0.09% and 0.19%.

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