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A selective multipath routing protocol for ubiquitous networks

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ABSTRACT

During the past years, ubiquitous networks have become an interesting topic for research due to their flexible and independent nature in terms of network infrastructure. A lot of effort has been made around the design of efficient routing protocols, mainly because of their unique characteristics, such as, dynamic topology, high mobility and limited bandwidth. In this paper, we propose a new routing protocol which is based on our Multipath-ChaMeLeon (M-CML) routing protocol. We perform a network optimization analysis of M-CML under a series of simulations taking into account three Quality of Service (QoS) metrics and we provide the results with statistical confidence interval by applying the *Wilcoxon signed-rank test* model. On top of the outcome of the analysis, we also apply an intelligent algorithm to enhance our protocol's effectiveness by reducing the improvident emission of data packets. The new protocol, named M-CMLv2, is compared to OLSR, AOMDV and M-CML using the NS-3 simulator. The acquired results indicate that M-CMLv2 reduces the redundant information, maintains good performance at successfully delivering packets with acceptable end-to-end delay, while at the same time, it reduces the network's routing load and the energy consumption of the nodes.

1. Introduction

Mobile Ad Hoc Networks (MANETs) can be utilized to establish an independent and purpose-built network which operates in a decentralized manner without relying on any pre-existing infrastructure. Under this light, MANETs are considered as a promising solution to address demanding scenarios aiming to provide public protection and disaster relief, especially in cases where traditional networks such as Long-Term Evolution (LTE) [1–3] or Terrestrial Trunked Radio (TETRA) [4] are not operational. Their flexible nature in terms of ease of installation enforces their applicability in a great range of instances, such as the dynamic networks with high mobility and large node density or static networks with small node density and medium/low mobility in addition to the strict energy constraint. MANETs can be applied in a variety of situations such as in military sector for day-to-day communications among soldiers, vehicles and central units, or in commercial sector for emergency communication scenarios, for instance, earthquakes, floods, tsunamis etc.

Due to the flexibility of the wireless technologies, Ubiquitous Networks can be utilized in territories with insignificant communication infrastructure. Their autonomous nature and their ability to be operating independently providing device-to-device (D2D) communication [5] without relying to any pre-existing infrastructure classifies them as an effective solution for addressing the requirements of emergency communication, since they can easily be deployed for Public Protection and Disaster Relief scenarios (PPDR) [6–8] happening in hostile and hazardous environments.

The MANET nodes are generally equipped with conventional Wi-Fi antennas, i.e., same antennas as used on today's smartphones which makes them susceptible to channel capacity and coverage limitations. These limitations, along with the presence of various obstacles, potential high node mobility and frequently changing topology of the network may lead to high packet loss and longer end-to-end delay. We can significantly improve such problems by designing efficient routing protocols in the network layer.

The routing protocols in MANETs are studied under two major categories, which are proactive and reactive, according to the routing algorithms that are used in route discovery process and data forwarding. Reactive protocols like the Ad Hoc On Demand Distance Vector (AODV) [9] and the Dynamic Source Routing (DSR) [10], maintain a sleep mode until it is triggered by a transmission request. This attribute allows them to sustain bandwidth availability and energy conservation. Conversely, proactive routing protocols such as the Optimized Link State Routing (OLSR) [11], support the constant exchange of control message between the network participants, as a mechanism to maintain the network topology awareness. Their table-driven functionality supports

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immediate exchange of data between the participating nodes. The emerging trade-off between the two routing protocol categories lies on the fact that while proactive protocols reduce the delay of transmission, the lack of energy conservation mechanisms caused by the constant exchange of control messages make them energy and bandwidth inefficient. On the other hand, reactive protocols support mechanisms to mitigate the routing overhead and thus reduce the bandwidth and energy consumption. However, their on-demand transmission architecture radically increases the latency and delay of transmission which makes it prone to errors and disconnections in cases of networks with high mobility.

Several multipath routing protocols have been developed that aim to solve the weaknesses which generally degrades single path routing protocol performance. Multipath routing can be used for efficiently solve the problems such as unstable links among the nodes in a network, high node mobility and increased latency. Hence, Quality of Service (QoS) metrics can be significantly enhanced by adapting a multipath approach which ultimately help the nodes to maintain their routing tables containing all the nodes participating on the network. At the same time, the periodic exchange of control messages contributes to the successful discovery of all possible routes without affecting the routing overhead or the energy costs [12].

A modified version of OLSR supporting multiple routes, called OLSRM, was proposed by Adoni and Joshi [13]. They used an energy aware metric for reducing the congestion in the network and balancing the load distribution, however, results were obtained only regarding the end-to-end delay where OLSRM performed better than OLSR. Another OLSR-based multipath solution was proposed by Yi et al. [14] that computes the routing tables following an on-demand manner. The results related to connection resilience and throughput indicated that their algorithm improved the performance of the OLSR routing protocol. The MP-OLSR protocol was compared to Dynamic Manet On-demand (DYMO) [15] protocol for smart city applications in [16]. It showed better performance during packet transmission and delivery exploiting its multipath policy, but on the other hand, it needs improvement when nodes are in idle mode, especially in low network traffic scenarios.

Authors in [17] considered NC-OLSR, a multipath extension of OLSR for flying ad-hoc networks. Their hybrid approach is based on random linear network coding which provides better performance than OLSR, however, scalability and energy consumption is not studied. In [18] the authors proposed a multipath and OLSR-based approach named MBQA-OLSR which considers a variety of metrics, i.e., node's idle time and lifetime, residual energy, and length of traffic queue in order to calculate the best path. According to their performance evaluation, results suggested that their approach behaves better in terms a series of QoS by increasing the traffic load, but there is no indication regarding its behavior in node mobility and higher density scenarios. Authors in [19] proposed a multipath extension based on the DSR routing protocol. ESIM-DSR performs the route selection by using the residual and transmission energy of a potential route. The simulation results are presented according to the average residual energy and the standard deviation of transmission energy which illustrate a better performance of their proposed approach against the default DSR. However, there is no comparison with other QoS metrics such end-to-end delay and packet delivery ratio to acquire a better understanding regarding their protocol's performance.

Another multipath routing approach is Ad Hoc On Demand Multipath Distance Vector (AOMDV) [20] which is the multipath version of the AODV routing protocol. This approach modifies the route discovery process giving the freedom to the receiver to reply to each routing RREQ message individually. Although this approach shows better behavior than AODV, it suffers from delay caused by intermediate nodes who trust untrustworthy path which does not provide connection to the destination. Authors in [21] proposed a cross-layer and AODV-based QoS aware multipath routing protocol, named QMR, which considers factors such as residual energy and signal strength. Although QMR showed good performance in simulations with different levels of mobility, there is no indication of how the protocol performs in terms of scalability. In [22], authors suggested an improved version of AOMDV, i.e., EA-AOMDV, that computes the multiple paths according to the energy in the nodes participating in the network. Their approach indicated better performance than AOMDV, however, authors did not study its behavior in high mobility scenarios.

The authors in [23] also proposed a multipath solution based on AOMDV protocol in 2017. The Fitness Function (FF-AOMDV) protocol aims to reduce the energy consumption by finding the best path between source and destination. FF-AOMDV was compared against the AOMDV and AOMR-LM and the performance is shown to be better in a series of QoS metrics. Moreover, there are other multipath routing protocols that consider QoS metrics such as delay, bandwidth and energy [24–26]. In these protocols, the decision taken by the receiver depends on QoS metric measurements gathered by the request packets before it replies back to the sender node. However, this approach increases the delay until the sender receives all the replies from the receiver in order to decide and select the most optimal path.

There are many challenges that increase the complexity in the design of a routing protocol. Within a MANET, nodes may join or leave the network at any given time increasing the probability of link instabilities, failures or abrupt disconnections. The factors such as the unpredictable node mobility, the energy restrictions, the inter-system interference, the propagation delay or the obstacles within a dynamic network environment, severely affect the optimal operation of the network. The challenge that arises here brings forward an optimization problem where the routing protocol needs to formulate strategies in order to adapt to the radical topology changes, and at the same time, addressing data transmission via optimal path discovery.

The contributions of this paper are threefold:

- We present the methodology to optimize and evaluate our Multipath-ChaMeLeon (M-CML) [27] routing protocol based on the approach of Gomez et al. [28] by studying three QoS metrics in a series of simulation scenarios. We apply statistical tests to the obtained results in order to present our scenario comparisons with statistical confidence.
- We apply the optimization configurations on our M-CML routing protocol. Furthermore, we propose and implement an improved version of our multipath algorithm aiming to enhance the performance by reducing the generation of duplicate packets.
- Finally, we evaluate the effectiveness of our new protocol, i.e., M-CMLv2, by comparing it to OLSR, AOMDV and its predecessor (M-CML) through a series of simulations considering two additional QoS metrics.

The paper is organized as follows: Section 2 provides a brief overview of OLSR and highlights the importance of multipath against single path routing protocol and describes the advantages of utilizing Expected Transmission Count (ETX) [29] instead of the traditional hop count metric. It also presents in detail the system model of our M-CML routing protocol. Section 3 describes the methodology followed for optimizing M-CML protocol, based on [28] and also presents the acquired simulation results with statistical confidence by applying the Wilcoxon signed-rank test model. We also propose a new intelligent multipath algorithm which is the basis for the proposed M-CMLv2 routing protocol. In Section 4, we compare the updated version (M-CMLv2) to its predecessor, i.e., M-CML, AOMDV and OLSR in two simulation scenarios by taking

Table 1
Standardization of generalized building blocks.

RFC 5148	Jitter considerations in mobile ad hoc networks
RFC 5444	Generalized MANET packet/message format
RFC 5497	Representing multi-value time in mobile ad hoc networks
RFC 6130	MANET neighborhood discovery protocol (NHDP)

into account five different QoS metrics. Finally, Section 5 concludes the paper by emphasizing the advantages and disadvantages obtained with our method and also provides the future works.

2. Multipath-ChaMeLeon framework

This section introduces an overview of OLSR, which is the base of M-CML, along with some of its core functionalities and attributes. Furthermore, the suitability of using multipath routing and ETX as link metric is also highlighted.

2.1. OLSR standardization and attributes

OLSR has been recognized as one of the most popular and extensively used proactive routing protocols created for MANETs (RFC 3626). It aims to have the most updated network information at any given time by constantly exchanging control messages among nodes forming a network and also forwards data through the best path which is based on a pre-defined metric. In particular, the network is flooded by nodes with link state information messages which consist of the periodic transmission of HELLO and Topology Control (TC) messages. All nodes maintain a list of their neighbor's address and next hop link interface.

The process of topology discovery is responsible for the network's topology map creation, while the link sensing and neighbor detection mechanisms populate a list of one and two hop neighbors. To address the overhead's impact caused by the periodic transmission of control messages, OLSR establishes an intelligent mechanism named MultiPoint Relay (MPR). The way MPRs are allocated primarily depends on node willingness forwarding the routing information to the rest of the participants, and is predetermined during the periodic exchange of HELLO messages.

The second version of OLSR, i.e., OLSRv2 [30], was released and introduced to the MANET community in April 2014 through the RFC 7181. The new protocol retains the same basic algorithms and mechanisms with its predecessor but, at the same time, it presents a modular and simpler approach compared to OLSR. In particular, OLSRv2 introduces a set of new generalized building blocks as presented in Table 1, standardized independently to support the implementation in other protocols as well. The proposed routing framework in this paper can be further implemented in OLSRv2 as part of additional modules.

There are limited studies on the OLSRv2 performance evaluation and comparison against OLSR or other routing protocols. However, according to [31,32], there is, in general, no significant difference between these two protocols in terms of, for instance, packet delivery ratio and overhead analysis of incoming and outgoing traffic per node. Therefore, we believe that the performance of M-CMLv2 will have a similar impact when it is based on OLSRv2.

2.2. Theoretical background

Multipath routing protocols can be employed to tackle instabilities such as node and link failures caused by higher nodes' mobility, energy constraints and dynamic topologies. Therefore, multipath mechanisms have been widely proposed in order to tackle the weaknesses in single path routing protocols and provide a robust solution to a variety of challenges due to the mobility, scalability and link instabilities of the network. The periodic exchange of control messages, which is the main characteristic of OLSR contributes to the fact that all nodes forming a MANET can create, maintain and update their routing table over time. Transmitting data through multiple paths can improve drawbacks caused by the constantly changing environments in which MANETs typically operate and enhance transmission reliability. On the other hand, the constant generation of redundant information combined with the bandwidth utilization are two inevitable parameters that should be taken into account during the design. By using multiple paths to transmit data, extra information is automatically transmitted throughout the network increasing the congestion level and the energy consumption [33].

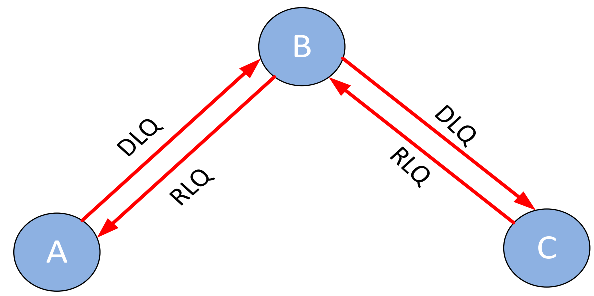

Fig. 1. ETX functionality.

Link metrics are important criteria used to define the optimal routes towards the destination and take decisions related to data transmission. As a result, they achieve the optimal performance of a routing protocol to improve the scalability and network capacity of data transmission. The majority of routing protocols in MANETs rely on the hop count metric which is the well known and widely used link metric in MANETs due to its simplistic nature. By the time the network topology is defined, hop count is used to calculate the shortest path from the source to the destination according to the number of hops and select the optimal path accordingly. It is obvious that the greatest advantage of hop count is that it is easy to calculate, since it does not take any other factors into consideration apart from the hops between the nodes. Therefore, it performs better in terms of end-to-end delay [34]. On the other hand, it does not consider the quality of the links among the nodes which, in a constantly changing network topology can be of vital importance. As the matter of fact, a route that minimizes the number of hops does not guarantee to provide the maximal throughput on a flow.

The need to identify more intelligent and effective mechanisms to improve the performance of MANETs has emerged the necessity of utilizing metrics which takes into account the quality of the links in order to determine the best path. In this light, ETX estimates the total re-transmissions demanded to transmit packets by measuring the rate of lost broadcast packets among pairs of nodes. The calculation of ETX is performed by each node broadcasting a probe packet in a predefined time period and by also sending packet including the number of probe packets successfully received by all neighbors during the last time period. Therefore, these probe packets constitute the base for all nodes to calculate the probe packet loss rate to and from their neighbors, having good knowledge of the quality of the links. Our routing protocol further improves and incorporates the extra values of ETX on its HELLO and TC messages, such that all nodes are aware of the link quality of their neighbors. As illustrated in Fig. 1, the loss rate can be calculated in both directions.

Node A to node B computes the Direct Link Quality (DLQ) as the probability of successful transmission over a time period. In the same way, Node B to node A calculates the Reverse Link Quality (RLQ). We can denote the ETX value [29] measured by node i at time t as:

$$ETX_i(t) = \frac{1}{RLQ_i(t) \times DLQ_i(t)} \quad \exists \begin{cases} RLQ_i(t) \in [0,1] \\ DLQ_i(t) \in [0,1] \end{cases} \tag{1}$$

where, $DLQ_i(t)$ is the ratio of the successfully received packets by node i divided by the total number of the generated packets; $DLQ_i(t)$ is the reverse deliver ratio. Hence, the product of $DLQ_i(t) \times DLQ_i(t)$ is the probability of a probe packet to be successfully sent and acknowledged by a node. According (1), in an ideal case, it is obvious that $RLQ_i(t) = 1$ and $DLQ_i(t) = 1$. In such cases, $ETX_i(t) = 1$ which indicates that the quality of the link is ideal to establish a perfect source to destination link.

We developed a multipath approach based on OLSR routing protocol in 2016, called M-CML [27], which exploits the attribute of the Expected Transmission Count instead of the default hop count metric. The main functionality of M-CML is the computation of multiple paths, according to the ETX instead of the traditional hop count metric. Parameters such as bit error rate and link quality are not evaluated on the default operation of OLSR protocol, increasing the possibility of broken links which makes the hop count metric not sufficient for reliable route selection. M-CML substitutes hop count with ETX, which is an intelligent alternative based on the number of successful transmissions. The main aim of this change is to decrease link errors probability and increase the performance and robustness of the protocol. A brief description of M-CML is given in the next section.

2.3. M-CML system model overview

As an overview, this section describes the implemented changes for the design of M-CML. M-CML uses ETX as its default metric for calculating the best route instead of the traditional hop count. The most optimal path is calculated based on the minimum ETX sum of a path. We have modified the ETX equation and make it in line with the specifications of [35]:

$$ETX_i(t) = RLQ_i(t) \times DLQ_i(t). \tag{2}$$

Furthermore, on top of the ETX implementation, M-CML employs a multipath advanced relay method, so as to eliminate the generation of redundant packets. The routing table of nodes comprising a MANET is maintained and updated by a set of next hop addresses and their corresponding ETX values categorized in ascending order according to the lowest values of ETX. Moreover, the data to be transmitted in the network is forwarded only to the routes carrying two most optimal values of ETX, i.e., two minimum ETX values. The reason of choosing the two minimum values is clearly to avoid flooding the network with redundant information. We next focus on presenting the process of calculating multiple paths and also describe the way a new entry is added to M-CML's routing table. Based on this process, we apply an improved algorithm which is proposed in Section 4. More information regarding the message format and message processing for M-CML can be found in [27].

2.3.1. Multipath routing

All nodes within a MANET create and maintain their routing tables so as to keep information about all the available routes to potential destination addresses in the network. The entries of the routing tables are constructed according to information obtained from local link and topology set information acquired through the periodic exchange of routing messages (HELLO and TC), following the specifications in RFC 3626. For our approach, M-CML enforces re-computation of routing tables whenever a change occurs in at least one of the Link Set, Neighbor Set, 2-hop Neighbor Set or Topology Set.

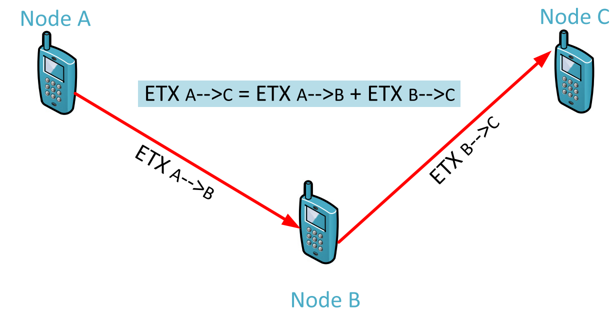

Fig. 2. Two hop neighbor set - ETX calculation for routing table computation.

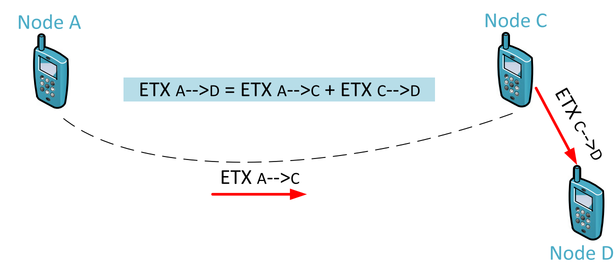

Fig. 3. Topology set - ETX calculation for routing table computation.

The ETX value in the routing table of all 1-hop neighbors is set to be equal to the ETX metric in the link tuple. Subsequently, the routing table for all the 2-hop neighbors gets an ETX value which equals to the best ETX value related to the corresponding 1-hop neighbor and on top of this the ETX value of the 2-hop neighbor tuple linked to this 1-hop neighbor is also added. Fig. 2 illustrates how ETX is calculated on a 2-hop Neighbor Set. For instance, node C is a 2-hop neighbor for node A. Therefore, in this case, the ETX value is equal to $ETX_{A\rightarrow C} = ETX_{A\rightarrow B} + ETX_{B\rightarrow C}$.

When the first part of calculating the ETX metric for both 1 and 2 hop neighbors is completed, we take advantage of the topology tuples to accommodate the remaining nodes. As a result, the ETX value for the remaining nodes of the network is calculated by taking advantage of the topology tuples. Here, the ETX metric equals the sum of ETX value recorded by the topology tuples and the ETX value related to that topology tuple. Fig. 3 illustrates an instance of simplifying the computation of ETX to the remaining 1 and 2-hop neighbors. Node D acquires the $ETX_{C\rightarrow D}$ by using the relevant topology tuple and adds it on top of summed ETX values stored in node A ($ETX_{A\rightarrow C}$).

The combination of ETX as a link metric and the multipath routing has led to the requirement of storing all multiple paths for all the recorded destination in the network in the M-CML routing table entry. Hence, M-CML has introduced three new entries compared to OLSR. Algorithm 1 describes the process when a new entry is added to M-CML's routing table:

- *Rdestaddress*: Destination address
- *Rnextaddresses*: The list next nodes addresses of N multiple and their respective ETX value listed in ascending order of ETX, i.e. $(Rnextaddr_1, ETX_1)$, $(Rnextaddr_2, ETX_2)$, ..., $(Rnextaddr_n, ETX_n)$, where $ETX_1 < ETX_2 < \ldots < ETX_n$.
- *Rdistance*: The optimal ETX_i value, i.e., $ETX_i = minimum \{ETX_1, ETX_2, \ldots, ETX_n\}$

3. M-CML network optimization

Routing messages in our protocol are considered as a key element which affects the network's efficiency and robustness. In an ideal scenario, a routing protocol should be able to compute and provide the most optimal routes with minimal consequences

Algorithm 1 Add entry in the routing table for M-CML.

```
Input: dst = Address of the destination
   nha = Addresses of next hop neighbors
   nma = The list of next nodes' addresses indicating the k
   multiple routes along with ETX values represented in
   ascending order
   etxmetric = Route's ETX value
   Rtable = Nodes' routing table
begin
entry ← Search_dst_in_Routing_Table(Rtable,dst);
  if (entry_exists) then
  set_of_nma  ← Get_next_addr_for_dst(entry);
    for each _nma ∈ set_of_nma then
      if (nma = nha) then
      etxsaved ← GetETXDistanceStoredinRtable(nma);
        if (etxsaved ≥ etxmetric) then
        Update_value_of_etx(nha,etxmetric);
        end
      end
    end
  if (nha ∄ set_of_nma) then
   Add_in_stored_nma(nha,etxmetric);
 end
  entry ← sort_etx_ascending_order(set_of_nma);
  Rtable ← UpdateEntry(entry);
   else if (there_is_no_dst ∄ in_Rtable) then
    entry ← CreateRtableEntry (dst, nha, etxmetric);
    Rtable ← GetEntry(entry);
   end
   return Rtable;
end
```

Table 2
M-CML configuration parameters .

M-CML parameters	1	2	3	4
HELLO_INTERVAL (s)	0.5	1	4	2
REFRESH_INTERVAL (s)	0.5	1	4	2
TC_INTERVAL (s)	1.25	2.5	10	5
NEIGHB_HOLD_TIME (s)	1.5	3	12	6
TOP_HOLD_TIME (s)	3.75	7.5	30	15
WILLINGNESS	AUT.	AUT.	AUT.	AUT.

on bandwidth, data latency, and battery consumption. In this context, this paper adapts the approach presented on [28], with the view to tune the parameter values of M-CML routing protocol, so as to optimize the network performance and ultimately confine the transmission of control messages. Authors in [28] have defined and studied a metric called Route Change Latency (RCL). RCL indicates the amount of time required to establish a new route that occurs after link failures in the OLSR protocol. The reason for choosing this metric is attributed to the fact that MANETs face performance instabilities and their performance depends on the protocol's parameter settings. Here, our aim is to study the performance of M-CML following these three approaches and evaluate the results.

3.1. Methodology

This section describes the methodology used to measure the performance of M-CML by applying three different configuration sets used as mechanisms to analyze the results [36]. We have defined a series of scenarios in order to study M-CML's behavior in different conditions, so as to conclude the most efficient parameters settings. Table 2 describes the various time intervals we use for our methodology. Configuration #4 contains the default parameters as in [27]. Here, the HELLO and TC intervals are 2 and 5 s, respectively. All other parameters are dependent on HELLO and TC intervals. Moreover, Configurations #1, #2 and #3 are based on the approach of [28].

Table 3
Scenarios details.

Scenario	Area size (m^2)	Node density	Speed (m/s)
S1	500 × 500	S = 6	1
		M = 10	5
		L = 16	10
S2	1500 × 1500	S = 16	15
		M = 26	20
		L = 36	25

3.1.1. Simulation environment

The performance evaluation of M-CML is performed by carrying out 72 different scenarios of emergency situations. The scenarios have been set to take into account two different network topologies, two levels of speed and three levels of node density. The main characteristics of the performance evaluation scenarios are presented in Table 3. Simulations are conducted through the use of the Network Simulator 3 (NS-3) [37,38], which can handle and accommodate simulations of multiple other routing protocols in MANETs. It can also be used to compare the proposed routing protocol.

In particular, the Random Waypoint Mobility (RWM) model is exploited as a suitable mobility standard that enables nodes to move in random directions within a pre-defined area. In addition, Random Mobility Allocator is employed to set up the initial positions of the nodes before the simulation part is triggered. The simulation runs in total for 230 s. The first 50 s are for warm-up and the rest 180 s are the actual simulation. In our scenarios, S represents cases with minimum number of nodes, L cases with large number of nodes and finally M is an intermediate situation. Furthermore, we vary the speed of nodes and categorize them in two different groups. The first three values in Table 3 represent *Low Mobility* (i. 1 m/s, ii. 5 m/s, iii. 10 m/s), while the rest three are considered as *High Mobility* (iv. 15 m/s, v. 20 m/s and vi. 25 m/s).

3.1.2. Network and communication model specifications

A wide range of available network simulators supporting experimentation with routing protocols in MANETs is offered in the research community. For the purpose of our simulations we are using 802.11a standard and modules of the wireless physical layer in order to provide high level of accuracy. In the network layer, our M-CML routing protocol is used, aiming to provide the most optimal paths for packet forwarding in the network topology. The User Datagram Protocol (UDP) has been used as the transport layer protocol which, in contrast to Transmission Control Protocol (TCP), provides a plain transmission model with no need of handshaking processes. The reason of using UDP is due to the fact that packet loss may occur during transmission process. Finally, Constant Bit Rate (CBR) is employed to generate the network load. The size of the CBR is set to 512 bytes. The number of CBR pairs, (nodes sending and receiving) is set to be equal to the half of the total number of nodes in each case. Hence, we always have to simulate an even number of nodes in our network.

3.1.3. Evaluation metrics

For the most optimal configuration of M-CML performance, we consider three QoS metrics in MANETs domain:

- Packet delivery ratio (PDR): The proportion of successful data packets delivered to the destination compared to the total generated data packets,

$$P = \frac{1}{F} \sum_{i=1}^{F} \frac{R_i}{S_i} \tag{3}$$

Table 4
Obtained results of PDR, NRL and E2ED QoS metrics for three different configurations of M-CML.

		M-CML			M-CML#3		
		PDR (%)	NRL	E2ED (ms)	PDR (%)	NRL	E2ED (ms)
Size	S1	96.47	0.166	1.226	96.06△	0.087▲	1.334△
	S2	78.78	0.297	4.919	73.83▲	0.180▲	7.489▲
Speed	Low	94.93	0.212	2.097	94.29△	0.109▲	2.575△
	High	80.32	0.251	4.047	75.60▲	0.158▲	6.247▲
Node density	S	94.08	0.173	2.433	91.52△	0.101▲	2.537△
	M	88.61	0.226	3.015	85.34△	0.129▲	4.323▲
	L	80.18	0.295	3.770	77.98▲	0.169▲	6.373▲
Total average		87.62	0.232	3.072	84.95△	0.133▲	4.411▲
		M-CML#1			**M-CML#2**		
		PDR (%)	NRL	E2ED (ms)	PDR (%)	NRL	E2ED (ms)
Size	S1	98.15△	0.649▲	0.845▲	98.03△	0.327▲	1.032▲
	S2	92.86▲	1.058▲	3.059▲	87.40▲	0.553▲	3.603▲
Speed	Low	97.60△	0.832▲	1.568▲	96.68△	0.420▲	1.879▲
	High	93.41▲	0.875▲	2.052▲	88.76▲	0.460▲	2.757▲
Node density	S	98.13▲	0.637▲	1.783▲	96.79▲	0.330▲	1.861▲
	M	96.74▲	0.832▲	2.177▲	92.76▲	0.431▲	2.320▲
	L	91.64▲	1.090▲	1.897▲	88.60▲	0.560▲	2.772▲
Total average		95.51▲	0.853▲	1.952▲	92.72▲	0.440▲	2.318▲

where, P is a fraction of successfully delivered packets, F is the total number of connection flows in the simulation, i is the flow ID. Here, R_i and S_i are the total number of packets received and the total number of packets transmitted in flow i, respectively.

- Average end-to-end delay (E2ED): The mean time required for the surviving data packet to traverse the distance from the source to the destination,

$$D = \frac{1}{N}\sum_{j=1}^{N}\left(T_{j,1} - T_{j,2}\right) \tag{4}$$

where, D is the average end-to-end delay and N is the total number of packets received successfully. Here, $T_{j,\,1}$ and $T_{j,\,2}$ are the time when a packet with ID j is received and the time when a packet with ID j is transmitted through a route, respectively.

- Normalized routing load (NRL): The sum of the transmitted control messages divided by the sum of the delivered data in bytes.

$$NRL = \sum_{i=1}^{F}\frac{C_{i,B}}{R_{i,B}} \tag{5}$$

where, $C_{i,\,B}$ and $R_{i,\,B}$ are the number of the transmitted control messages and the received data messages in bytes, respectively.

3.2. Performance evaluation

We implement the aforementioned scenarios to evaluate the performance of M-CML following the three approaches presented in Table 2. The complete results of the performed simulations are illustrated in Appendix A (Table A.6). This section classifies the obtained results according to the three considered criteria: i) Network area size, ii) Node mobilities, and iii) Node density.

The overall performance of M-CML protocol following the three approaches is presented in Table 4. Since we want to provide our scenario comparisons with statistical confidence, statistical tests are applied to the results obtained by the simulations. Hence, we take advantage of the *Wilcoxon signed-rank test model* [39] which is a non-parametric test. In order to guarantee that our distributions are statistically different in case that result in *p-value* is lower than 0.05, we have set the confidence level to 95%, *p-value* = 0.05. If a result of a particular M-CML configuration is better than other one but not with a statistical difference, it is presented with a white triangle (△). Otherwise, if it is significantly better, it is presented with a black triangle (▲).

3.2.1. Performance analysis under various network size

In this section, we discuss the results obtained based on the different network sizes considered in our simulation scenarios.

- With regards to PDR, there is a similar behavior among all different versions of M-CML for Scenario S1, by successfully exchanging more than 96% of the generated packets. M-CML differs less than 1% from M-CML#3 and approximately 2% for the other two configurations. However, in Scenario S2 it can be observed configurations #1 and #2 perform significantly better than the rest. The best results were performed by M-CML#1 (92.86%) and M-CML#2 (87.40%) in contrast to M-CML (78.78%) and M-CML#3 (73.83%).
- The NRL calculation in S1, indicated a decrease of 47.5% between M-CML and M-CML#3. In addition, M-CML#1 and M-CML#2 generated 291% and 97% more routing load respectively compared to M-CML. Similar pattern is followed for S2, where the comparison of M-CML with M-CML#3, M-CML#1 and M-CML#2 shows a decrease of 39% and a rise of 256% and 86% respectively.
- In terms of E2ED, it can be stated that M-CML and M-CML#3 showed roughly equal behavior for S1 with only 0.1 ms difference for M-CML. M-CML#1 and M-CML#2 performed slightly better than M-CML where the delay was decreased by 0.38 ms for the former and by 0.19 ms for the latter. Looking at S2, M-CML#3 had the worst performance by transmitting packets with 7.489 ms of delay, M-CML had a delay of 4.919 ms and M-CML#2 a delay of 3.603 ms. M-CML#1 clearly outperformed the other three by delivering packets with 3.059 ms delay.

It can be stated that for small areas M-CML#3 maintains a good balance among the three performance indicators by having approximately similar PDR values to the other three M-CML configurations, the least generated NRL and acceptable delay of 1.334 ms. For larger areas, we can observe that it behaves slightly worse than M-CML for PDR, better in terms of NRL, but the delay is too high as a result of the less frequent updates of the routing table.

3.2.2. Performance analysis under various node mobilities

In this section, we describe the results obtained by varying the participating user's speed. In particular, we observe the following.

- The PDR indicator for the *Low Mobility* category, M-CML (94.93%) and M-CML#3 (94.29%) have roughly same performance with only 0.64% and at the same time M-CML#1

(97.60%) along with M-CML#2 (96.68%) deliver almost the same percentage of packets. However, as the value of speed increases (*High mobility*), the percentage of successful packet delivery decreases for all M-CML configurations. More specifically, the PDR drops to 75.60%, 80.32%, 93.41% and 88.76% for M-CML#3, M-CML, M-CML#1, M-CML#2, respectively.

- In terms of NRL there is no significant difference in the generated routing load of each individual version of M-CML between low and high mobility scenarios. M-CML#3 outperforms M-CML by generating approximately half the routing load of M-CML for *Low Mobility* and 1.6 times less for *High Mobility*. Subsequently, the generated routing load for M-CML#1 and M-CML#2 is four and two times higher than M-CML in the two mobility categories, respectively.
- With regards to E2ED, it can be stated that the best performance is achieved by M-CML#1 with 1.568 ms (*Low Mobility*) and 2.052 ms (*High Mobility*) and M-CML#2 with 1.879 ms (*Low Mobility*) and 2.757 ms (*High Mobility*). M-CML follows with 2.097 ms (*Low Mobility*) and 4.047 ms (*High Mobility*) and finally M-CML#3 with 2.575 ms (*Low Mobility*) and 6.247 ms (*High Mobility*). It is obvious that the higher the mobility of the nodes is, the greater delay we experience when packets are transmitted in the network.

Therefore, under the low mobility scenarios, M-CML#3 clearly has the same performance to M-CML for PDR, i.e., only 0.5 *ms* higher E2ED and half of the NRL, which demonstrates that it a better solution for such scenarios. Moreover, M-CML#3 has negligible difference in terms of PDR and E2ED compared to M-CML#1 and M-CML#2 and much better NRL. On the contrary, when transmitting in high mobilities, M-CML#3 exchanges only 5% less data packets than M-CML with better NRL, but the E2ED is quite high. At the same time, the other two versions of M-CML manage to deliver more data packets, with less E2ED, but with significantly higher NRL.

3.2.3. Performance analysis under various user densities

The number of nodes forming a MANET directly affects the operation and scalability of routing protocols used in these types of networks. In this section, we have categorized our simulations in agreement with the node density; *Small* (6 and 16 nodes), *Medium* (10 and 26 nodes) and *Large* (16 and 36 nodes). By studying Table 4, following are our observations.

- Concerning the PDR, we can depict that for all configurations, the percentage of successfully delivered packets decreases by increasing the number of nodes which participate in the network. It drops from 94.08% to 80.18%, 98.13% to 91.64%, 96.79% to 88.60% and 91.52% to 77.98% for M-CML, M-CML#1, M-CML#2 and M-CML#3, respectively. It is noticeable that the difference between M-CML and M-CML#3 for the three different user density categories is only 3%.
- Looking at the NRL indicator, the generated routing load gets higher for the four M-CML versions as the user density increases. However, it can be observed that M-CML#3 performs better compared to the other three M-CML configurations by producing 1.75 times less routing overload than M-CML. M-CML#2 and M-CML#1 generate 1.91 and 3.68 times more routing load than M-CML, respectively.
- Regarding the E2ED, we observe that the delay experienced by nodes increases with the user density. For the *Small* density category, we have a similar performance for M-CML and M-CML#3. However, M-CML shows 1.308 ms and 2.603 ms less delay than M-CML#3 for the *Medium* and *Large* densities, respectively. The best performance is achieved by M-CML#1 with an average of 1.952 ms delay followed by M-CML#2 with an average of 2.317 ms delay.

Hence, in scenarios with small number of nodes the difference of the successfully packets delivered between M-CML#3 and M-CML is less than 3%. With regards to E2ED the difference is negligible and in terms of NRL, M-CML#3 performs significantly better. For the other two node density categories, M-CML#3 delivered approximately the same number of packets, whereas it generated much less NRL. Moreover, the E2ED was higher, especially in the *Large* density, due to its less frequent time intervals for the routing messages. Although, M-CML#1 and M-CML#2 delivered the largest number of packets with less delay, the generated NRL was extremely high.

3.2.4. Overall performance

This section highlights an overall performance picture according to the results obtained by each of the M-CML configurations. According to Table (last rows), there is no significant difference on the successfully delivered data packets between M-CML#3 and M-CML. M-CML#3 performs significantly better than M-CML in terms of NRL by using the network resources more efficiently but data packets take more time to reach the destination. However, the average E2ED is mainly increased due to scenarios that consider big boundaries, large densities and high mobility. Regarding M-CML#1 and M-CML#2, both perform better than the other two versions in terms of PDR and E2ED, however, the network routing load is significantly higher, which consumes a lot of bandwidth in the network.

Therefore, in cases where we need to deploy a MANET in fairly small areas with low mobility and medium node density M-CML#3 is classified as an ideal candidate to operate and perform reliably and smoothly. In the following subsection, we propose M-CMLv2 routing protocol which is based on our previous analysis. M-CMLv2 is characterized by two major modifications compared to M-CML aiming to improve its operational efficiency. The first addition is the incorporation of M-CML#3 configurations in the new version and the second is the proposal of a new logic on our routing algorithm which calculates the multiple paths in a more efficient manner.

3.3. Multipath ChaMeLeon version 2

Multipath routing protocols can be employed to tackle challenges created by link instabilities caused by environmental conditions. However, it is obvious that implementing a routing protocol operating in a multipath manner has some significant drawbacks related to higher duplicate data packet generation, traffic congestion in the network and high energy consumption. On this note, we have modified the operation of our M-CML routing protocol in a way of taking advantage of the multiple routes only if it is absolutely necessary. Section 2 explained the routing operation of M-CML system model in detail. Our main aim is to modify the way the multipath method is performed, reduce the generation of redundant duplicate packets, and apply the improved algorithm on top of the changes that we considered in the previous section.

In order to further develop the operational efficiency of M-CML, we now propose an extended version of M-CML named M-CMLv2. Here, M-CMLv2 protocol exploits the attributes of M-CML's system model, presented in Section 2, and aims to enhance its performance by applying the following changes:

- Following our analysis in previous section, M-CMLv2 utilizes the M-CML#3 configuration set, with the view of handling the generated routing load more effectively in the network.
- M-CMLv2 employs the improved multipath algorithm for selectively calculating multiple paths in a more efficient way, acting as a single path or multipath routing protocol depending on the quality of the links. This way, we aim to reduce improv-

ident emission of duplicate packets which impacts the network congestion and the nodes' energy consumption.

Algorithm 1 described how a new entry is added to M-CML's routing table. In particular, the set of next hop addresses are listed in an ascending order based on their ETX values. Upon transmitting data packets from source to destination, a gateway list is responsible for allocating the corresponding routing entry to the relevant destination, then parsing the ETX values which have been listed in ascending order and finally transmitting the information according to the two minimum ETX values. This concept has been enhanced with the logic described in Algorithm 2. Each time a node requests for a route towards the destination, it first calculates all next hops corresponding to that destination. In the case that there is not any available next hop, the packet is eventually dropped. Otherwise, node either transmits data using the two minimum values of ETX following the initial approach of M-CML, or dynamically decides to transmit data using a single path only if the ETX value is on its minimum value, i.e., ETX=1. This can reduce the unnecessary copies of the same packets which are distributed throughout the network due to the multipath attributes of the protocol and, at the same time, confine the energy consumption. Moreover, during the scenarios where the distance among source and destination is limited and the successful delivery of HELLO messages is high, we aim to eliminate the improvident emission of redundant information.

Algorithm 2 Packet forwarding method.

Input: n - Maximum number of next hops
D_j = Number of next hops per destination
RE = Routing entry (destination, next address, ETX and local interface addresses
begin
  Calculate D_j $\forall$ RE $(RE_1\ , RE_2\ \ldots\ RE_j)$ **where** (0 <= j <= n)
    if $j = 0$ **then**
      ERROR "No ROUTE to the destination";
    else if j$\neq$ 0 & ETX = 1 **then**
      Forward packet to D_0;
    else $\forall$ RE (D_j, ETX_j) **Forward packet to** D_0 & D_1;
  end
end

The next section describes the performance evaluation of M-CMLv2 in comparison to its predecessor M-CML, OLSR, and AOMDV.

4. Performance evaluation

In the light of evaluating the performance of proposed routing protocol, i.e., M-CMLv2, we have defined two simulation scenarios.

Similar to our initial scenarios, we will investigate the performance of M-CMLv2 by randomly distributing the nodes across the simulation area. The distributed nodes will be moving using the RWM model which allows them to create random mobility patterns based on the defined speeds and pause times.

For the purpose of packets transmission, we exploit the Constant Bit Rate (CBR) traffic type which is suitable for audio and voice applications with low latency. The packet size is fixed at 256 bytes and at the rate of four packets per second. Finally, we are using Orthogonal Frequency Division Multiplexing (OFDM) at a 6 Mbps rate for the physical layer modulation method following IEEE 802.11a standard. Our aim is to compare and evaluate M-CMLv2 to its predecessor M-CML, AOMDV and the default version of OLSR. The next section presents the QoS metrics we took into account for evaluation purpose and the two considered scenarios.

Table 5
Simulation set.

Network parameters	Scenario 1	Scenario 2
Network topology	750 m × 750 m	750 m × 750 m
Simulation time	300 s	300 s
Warm-up time	50 s	50 s
Node speed	3, 6, 9, 12, 15, 18 m/s	5 m/s
Channel bandwidth	6 Mbps	6 Mbps
Carrier frequency	5 GHz	5 GHz
Propagation model	Friis	Friis
MAC layer	IEEE 802.11a	IEEE 802.11a
Number of nodes	15	10, 12, 16, 20, 24, 30
Source-sinks pairs	3	5
Initial energy	50 Joules	50 Joules
CBR packet size	256 bytes	256 bytes
CBR data rate	4 packets/sec	4 packets/sec

In the first scenario, we study the behavior of the protocols in a variety of node speeds. In total, we have a constant number of 15 nodes randomly distributed in area of 750 m × 750 m, and a predefined three number of pairs as sources and destinations within the network. Finally, the nodes' speed varies from 3 m/s to 18 m/s, while the experiments run for 250 simulation seconds time plus 50 s as an initial warm-up time.

In the second scenario, we vary the number of nodes participating in the network from 10 to 30 randomly distributed in an area of 750 m × 750 m. We have a constant speed of 5 *m/s* and there are five pairs as source and destination within the network. The simulation time is set to 250 s with 50 s as an initial warm-up. The characteristics of the two considered scenarios are summarized and presented in Table 5.

4.1. Simulation results

This section presents the results obtained from the simulation of the scenarios described above and it discusses the performance of the routing protocols according to specific QoS metrics. In addition to the QoS metrics utilized in Section 3, we also consider the nodes energy consumption as well as the number of duplicated packets generated during the simulation time. We present our results with 95% confidence interval for both scenarios. Below we describe the additional QoS mechanisms taken into consideration for performance evaluation of the proposed method.

- Energy consumption (EC): The amount of energy consumed by a node n_i during the simulation time is set as $E(n_i)$,

$$E(n_i) = E_{tx}(n_i) + E_{rx}(n_i) + E_o(n_i), \tag{6}$$

  where, $E_{tx}(n_i)$), $E_{rx}(n_i)$) and $E_o(n_i)$ are the amount of energy node n_i wasted for transmitting, receiving and overhearing packets, respectively.
- Duplicate packets (DP): It is the number of same packets transmitted in the network as a result of the multipath functionality.

4.1.1. Packet delivery ratio

Figs. 4 and 5 illustrate the performance of M-CMLv2 versus OLSR, AOMDV and M-CML routing protocols. Here, M-CML shows a significant stability in both figures indicating a robustness against the varying speed of nodes and density, respectively. This can be attributed to the fact that M-CML exploits its ability to transmit data using the two most optimal paths based on the ETX values. On the other hand, M-CMLv2 performs better than OLSR for scenarios with low speeds and small sized networks. In particular, M-CMLv2 performs better compared to OLSR for speeds up to 9 m/s and for network size up to 16 nodes.

Furthermore, the overall PDR performance of M-CMLv2 is better than AOMDV irrespective of node density and mobility variations.

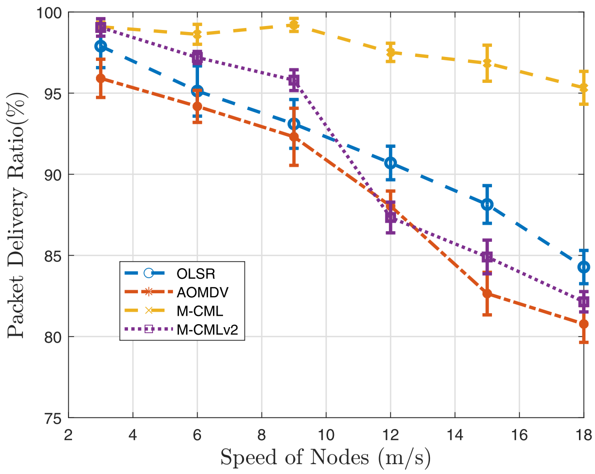

Fig. 4. Measurement of packet delivery ratio *vs.* various speeds of nodes.

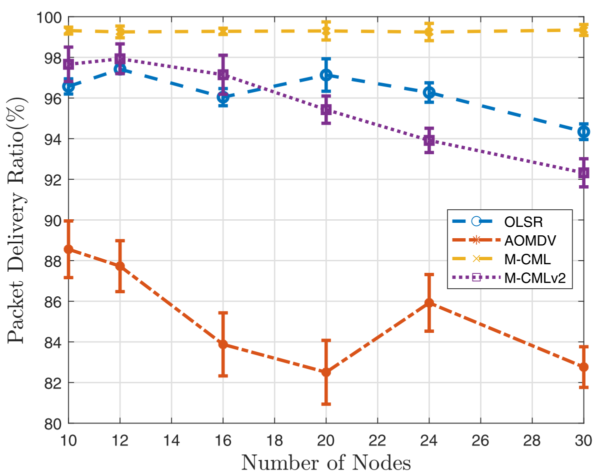

Fig. 5. Measurement of packet delivery ratio *vs.* various node densities.

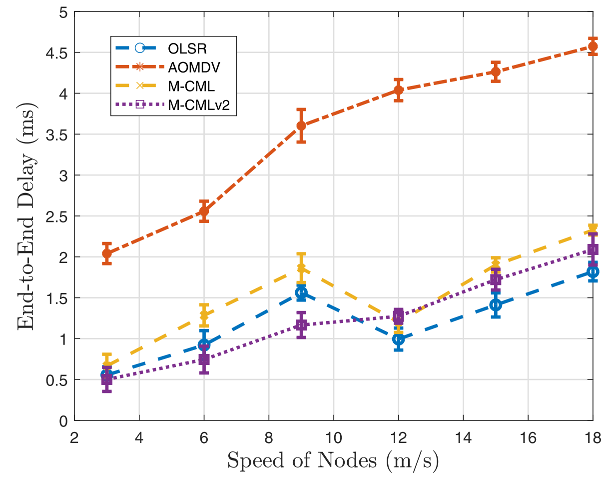

Fig. 6. Measurement end-to-end delay *vs.* various speeds of nodes.

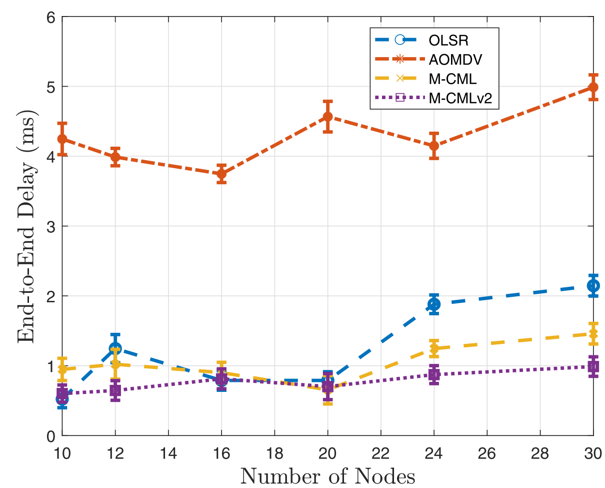

Fig. 7. Measurement of end-to-end delay *vs.* various node densities.

For instance, when the speed of node is 9 m/s, the proposed M-CMLv2 delivers 5% more packets successfully. Similarly, as shown in Fig. 5, when the node density is 24, M-CMLv2 could deliver 8% more packets than AOMDV.

The combination of an intelligent routing metric combined with its attribute to selectively behave as a multipath or single path protocol endorses its effectiveness over OLSR and AOMDV. However, as the size of the network and/or the speed of nodes increases, its functionality to exchange routing messages in a more slow-paced manner affects the efficiency of the protocol. This creates network instabilities as nodes may join or leave the network at any given time, while the routing protocol is not updated accordingly on time.

4.1.2. End-to-End delay

Examining the end-to-end delay indicator, it can be observed that when the speed of nodes increases, the E2ED gradually rises affecting the performance of all four routing protocols. In Fig. 6, all protocols have similar behavior for 3 m/s speed except AOMDV which results higher delay. The M-CMLv2 performs better than M-CML and OLSR for speeds up to 10 m/s, whereas its performance is slightly decreased for higher speeds in comparison to OLSR. However, its performance remains better than MCML in higher node mobility. This can be attributed to the characteristic of M-CMLv2 that reduces the generation of unnecessary duplicate packets causing less congestion to the network, which leads to reduced end-to-end delay. Furthermore, the proposed M-CMLv2 routing protocol performs significantly better, i.e., more than 2 *ms* in average, than AOMDV protocol.

For Scenario 2 in Fig. 7, where the numbers of nodes increases gradually, M-CMLv2 shows a stable behaviour maintaining E2ED below 1 *ms* for all node densities in contrast to OLSR, AOMDV and M-CML, which reach a peak of 1.9 ms, 4.98 ms and 1.45 ms, respectively.

4.1.3. Normalised routing load

Figs. 8 and 9 show the effect of speed and node density on the normalized routing load. It can be clearly stated that M-CMLv2 outperforms OLSR, AOMDV and M-CML in both scenarios. For Scenario 1, M-CMLv2 produced 0.99, 0.73 and 1.58 less NRL than OLSR, AOMDV and M-CML routing protocols, respectively. For Scenario 2, M-CMLv2 generated 0.93, 0.46 and 1.25 less NRL than OLSR, AOMDV and M-CML routing protocols, respectively. Although the ETX metric which is incorporated in the routing messages of M-CML and M-CMLv2 can increase the routing load, M-CMLv2 produces less NRL because it generates less routing messages according to the optimization method described in Section 3.

4.1.4. Energy consumption

Concerning the energy consumption by each node in both scenarios, M-CML shows the worst performance compared to all the considered protocols. For Scenarios 1 and 2, M-CMLv2 has almost two times less energy consumption compared to its predecessor

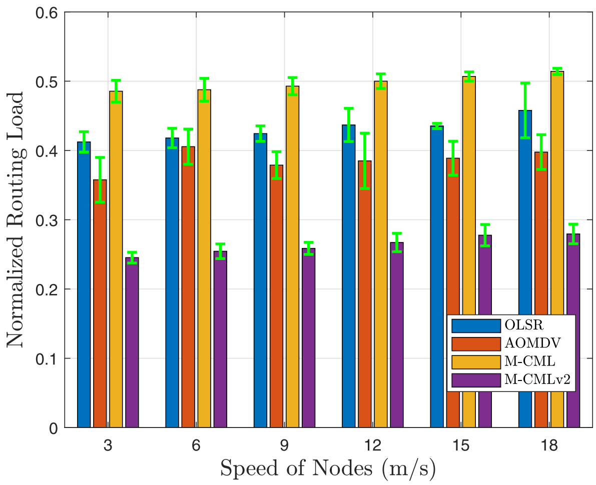

Fig. 8. Measurement of normalized routing load vs. various speeds of nodes.

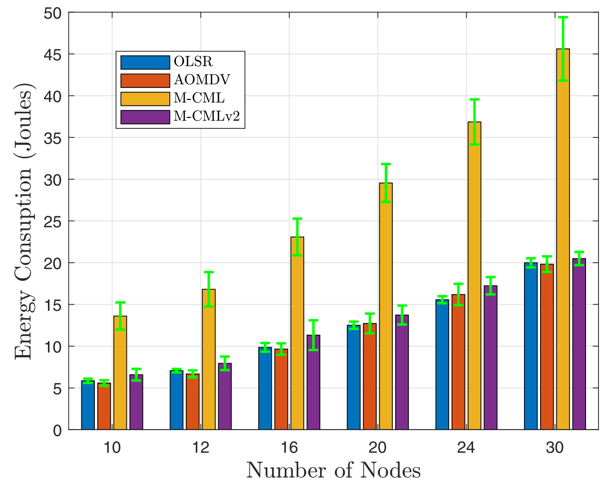

Fig. 11. Measurement of total energy consumption vs. various node densities.

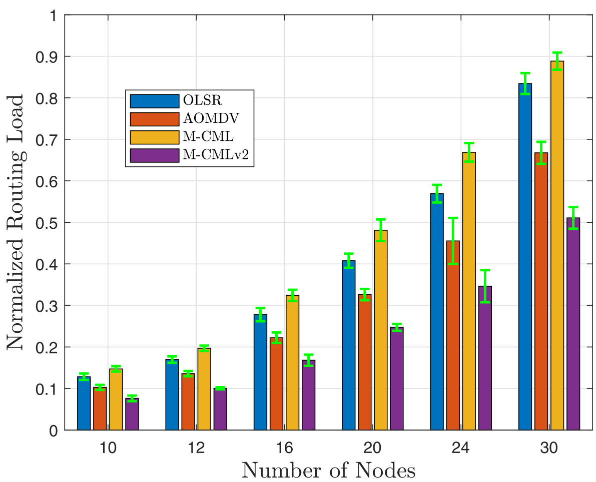

Fig. 9. Measurement of normalized routing load vs. various node densities.

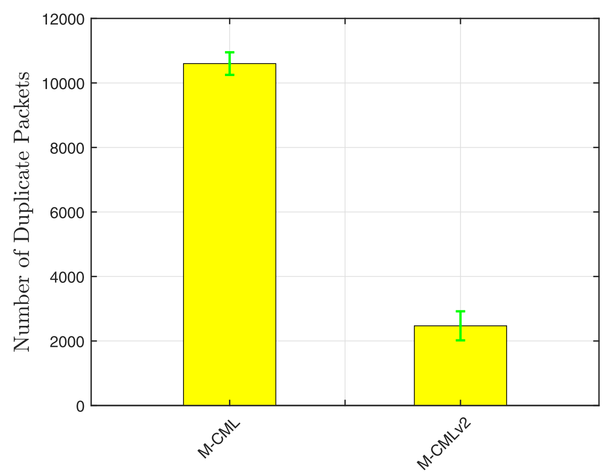

Fig. 12. Measurement of total duplicate packets for Scenario 1.

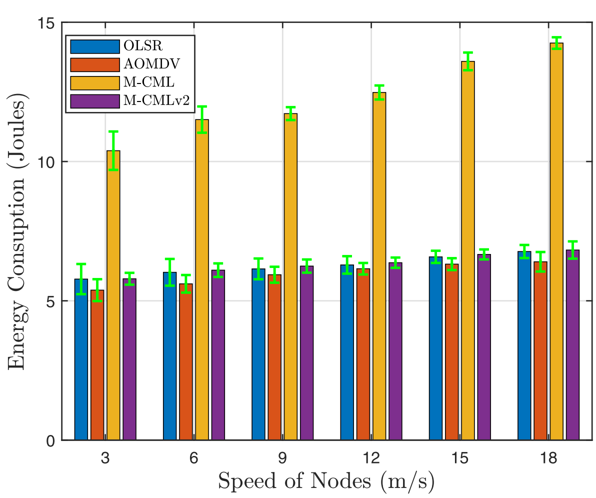

Fig. 10. Measurement of total energy consumption vs. various speeds of nodes.

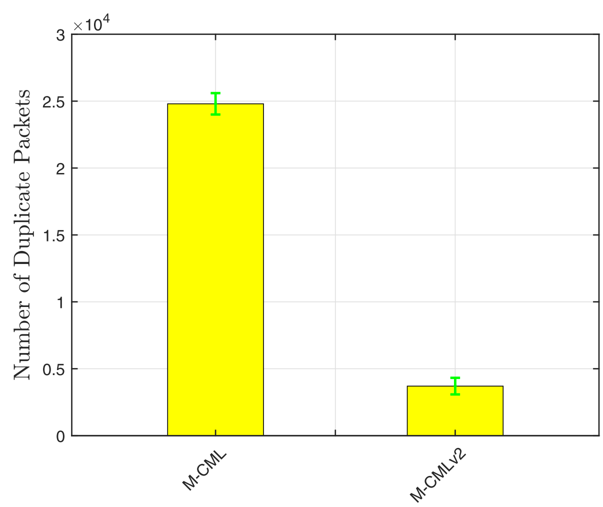

Fig. 13. Measurement of total duplicate packets for Scenario 2.

and slightly more than OLSR and AOMDV which can also be observed in Figs. 10 and 11. By adding a more intelligent algorithm for calculating multiple paths can lead to significant energy reduction because the nodes compute additional paths only when it is needed. Furthermore, although M-CMLv2 operates as a multipath protocol, depending on the network conditions, it has similar performance to OLSR and AOMDV in terms of energy consumption. The reason is that AOMDV, as a reactive routing protocol, has to process lower number of routing message. Furthermore, M-CMLv2 does not emit control messages as often as OLSR following the network optimization in Section 3.

4.1.5. Duplicate packets

The last QoS metric we considered is the generation of the duplicate data packets which is depicted in Figs. 12 and 13. We observe that M-CMLv2 generated approximately 4.3 times less and 6.6 times less duplicate packets than M-CML for Scenario 1 and Scenario 2, respectively. This can be attributed to the characteristic of M-CMLv2 that operates on a multipath mode only when it is required according to the quality of the links among the nodes in the network by exploiting the multipath routing algorithm as discussed in Section 3.3.

5. Conclusion

We first performed a network optimization analysis of multipath routing protocol M-CML under a series of simulations taking into account three QoS metrics including the results with statistical confidence interval which was obtained by applying the *Wilcoxon signed-rank test* model. On top of the outcome of the analysis, we also applied an intelligent algorithm to enhance the effectiveness of the proposed routing protocol by reducing the improvident emission of data packets. Secondly, we proposed an improved version of M-CML routing protocol based on various QoS metrics in different network scenarios. The new routing protocol, i.e., M-CMLv2, was compared to OLSR, AOMDV and M-CML protocols using intensive simulation results. The acquired results in terms of PDR, NRL, E2ED, EC and DP suggested that the M-CMLv2 reduces the redundant information, maintains good performance at successfully delivering packets with acceptable end-to-end delay. Moreover, it helped to reduce the routing load within the network and the energy consumption of the nodes simultaneously. As a future work, we will develop the testbed for M-CMLv2 to implement in post-disaster network scenario and we also further investigate on M-CMLv3 which will be based on OLSRv2.

Acknowledgment

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Appendix A. Complete simulation results

Table A.6 presents in detail the results of PDR, NRL and E2ED we obtained from the simulations in Section 3.

Table A.6
Complete results of PDR, NRL and E2ED QoS metrics for 3 different configurations of M-CML.

			M-CML			M-CML#3			M-CML#1			M-CML#2		
Size	Node density	Speed	PDR (%)	NRL	E2ED (ms)	PDR (%)	NRL	E2ED (ms)	PDR (%)	NRL	E2ED (ms)	PDR (%)	NRL	E2ED (ms)
S1	S	Low	98.93	0.115	0.912	98.87	0.057	0.718	99.11	0.467	0.668	98.88	0.233	0.798
			98.76	0.114	0.701	98.85	0.058	0.947	99.11	0.455	0.716	98.93	0.228	0.813
			98.93	0.115	0.596	98.88	0.058	0.752	98.23	0.462	0.532	97.34	0.231	0.602
		High	95.54	0.118	0.951	94.47	0.061	0.972	98.75	0.461	0.783	97.04	0.233	0.751
			96.19	0.119	0.975	94.24	0.063	1.015	96.89	0.466	0.703	98.42	0.233	0.873
			93.96	0.121	1.088	92.78	0.066	1.009	98.12	0.471	0.752	97.73	0.241	0.909
		Average	97.05	0.117	0.871	96.34	0.061	0.902	98.36	0.463	0.692	98.05	0.233	0.791
	M	Low	99.25	0.151	0.581	99.11	0.076	0.559	98.93	0.616	0.584	99.11	0.305	0.555
			99.05	0.156	1.057	98.64	0.079	1.211	98.45	0.626	0.748	98.09	0.314	0.916
			98.36	0.157	1.271	97.98	0.083	1.892	97.45	0.614	0.788	98.99	0.311	0.991
		High	96.05	0.162	1.374	96.56	0.088	1.367	98.04	0.623	0.773	98.54	0.314	1.119
			93.26	0.171	1.657	94.82	0.092	1.623	98.23	0.626	0.852	97.23	0.319	1.023
			91.33	0.178	1.671	94.73	0.097	1.814	97.52	0.631	0.928	98.91	0.329	1.279
		Average	96.21	0.162	1.268	96.97	0.085	1.411	98.1	0.622	0.778	98.47	0.315	0.98
	L	Low	99.11	0.207	0.769	99.05	0.103	0.612	99.05	0.838	0.747	98.43	0.417	0.786
			98.99	0.214	0.995	98.88	0.109	1.411	98.36	0.856	0.767	98.02	0.428	0.775
			98.87	0.217	1.754	96.27	0.112	1.917	97.31	0.856	1.063	96.34	0.431	1.257
		High	95.75	0.223	1.852	94.81	0.118	1.997	96.79	0.859	1.039	97.32	0.436	1.452
			93.17	0.229	2.012	92.05	0.122	2.089	98.24	0.874	1.424	98.33	0.445	1.858
			91.08	0.235	1.853	88.22	0.124	2.113	98.17	0.882	1.356	96.97	0.449	1.833
		Average	96.16	0.221	1.539	94.88	0.114	1.689	97.98	0.861	1.066	97.56	0.434	1.327
S2	S	Low	97.45	0.176	1.961	98.65	0.088	1.649	98.64	0.725	1.522	98.81	0.381	1.649
			97.91	0.201	2.717	93.46	0.102	3.161	98.87	0.781	3.224	98.84	0.393	1.755
			96.39	0.215	4.193	92.26	0.116	4.503	98.01	0.787	1.847	97.83	0.406	3.877
		High	92.74	0.248	4.706	81.34	0.149	5.037	97.61	0.846	3.443	96.11	0.449	3.114
			88.95	0.261	5.154	78.53	0.193	5.296	97.12	0.863	3.314	92.15	0.458	3.525
			73.24	0.282	5.242	75.99	0.209	5.392	97.16	0.867	3.899	89.42	0.484	3.672
		Average	91.11	0.231	3.995	86.71	0.142	4.173	97.91	0.811	2.874	95.52	0.428	2.932
	M	Low	96.07	0.249	2.561	93.19	0.121	2.511	98.11	1.002	2.795	97.91	0.509	3.191
			90.14	0.254	4.007	94.62	0.132	3.539	98.33	0.988	2.755	98.47	0.504	3.888
			85.34	0.282	4.779	84.25	0.149	5.212	96.34	1.041	2.901	88.32	0.538	3.046
		High	77.38	0.292	4.489	66.52	0.177	7.991	97.21	1.045	2.888	76.25	0.554	3.899
			65.27	0.316	6.291	53.07	0.214	10.432	92.06	1.077	4.351	82.14	0.575	3.635
			71.92	0.352	6.446	50.59	0.247	13.732	90.32	1.103	4.039	79.21	0.604	4.309
		Average	81.02	0.291	4.762	73.71	0.173	7.236	95.39	1.042	3.288	87.05	0.547	3.661
	L	Low	98.71	0.312	1.614	95.91	0.153	1.462	98.03	1.237	1.717	98.59	0.613	2.262
			92.56	0.328	2.421	89.12	0.173	6.329	97.56	1.298	2.136	97.03	0.651	2.078
			64.07	0.361	4.874	69.32	0.196	7.982	87.05	1.329	2.715	80.31	0.682	4.583
		High	47.37	0.381	7.378	40.83	0.226	10.432	81.14	1.338	3.525	71.24	0.702	4.405
			42.61	0.405	9.597	34.33	0.278	17.132	75.74	1.356	3.836	68.31	0.729	5.061
			39.97	0.439	10.124	37.02	0.324	23.011	72.34	1.366	4.165	62.41	0.739	6.918
		Average	64.21	0.371	6.001	61.08	0.225	11.058	85.31	1.321	3.015	79.64	0.686	4.218
Total Average			87.62	0.232	3.072	84.95	0.133	4.411	95.51	0.853	1.952	92.72	0.44	2.318

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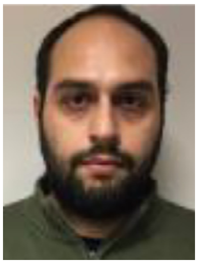

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