CE-OLSR: a Cartography and Stability Enhanced OLSR for Dynamic MANETs with Obstacles

Abdelfettah Belghith[1] and Mohamed Belhassen[1]
[1] HANA Research Group, University of Manouba
Tunisia Tunisia
[e-mail: abdelfattah.belghith@ensi.rnu.tn, mohamed.belhassen@hanalab.org]
*Corresponding author: Abdelfettah Belghith

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Abstract

In this paper, we propose a novel routing protocol called the Cartography Enhanced OLSR (CE-OLSR) for multi hop mobile ad hoc networks (multi hop MANETs). CE-OLSR is based on an efficient cartography gathering scheme and a stability routing approach. The cartography gathering scheme is non intrusive and uses the exact OLSR reduced signaling traffic, but in a more elegant and efficient way to improve responsiveness to the network dynamics. This cartography is a much richer and accurate view than the mere network topology gathered and used by OLSR. The stability routing approach uses a reduced view of the collected cartography that only includes links not exceeding a certain distance threshold and do not cross obstacles. In urban environments, IEEE 802.11 radio signals undergo severe radio shadowing and fading effects and may be completely obstructed by obstacles such as buildings.

Extensive simulations are conducted to study the performances of CE-OLSR and compare them with those of OLSR. We show that CE-OLSR greatly outperforms OLSR in delivering a high percentage of route validity, a much higher throughput and a much lower average delay. In particular the extremely low average delay exacerbated by CE-OLSR makes it a viable candidate for the transport of real time data traffic in multi hop MANETs.

Keywords: OLSR Protocol, network cartography, MANETS, routing validity, stability routing, obstacle avoidance.

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This paper integrates obstructing obstacles and their handling by CE-OLSR, and includes an extensive state of the art, a propagation model with obstacles and a more extensive simulation set using scenarios including obstacles.

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1. Introduction

Routing in wireless multi-hop mobile ad hoc networks (MANETs) represents one the main tasks to be efficiently conceived for these networks to be able to deliver adequate or even acceptable throughput and end to end average delay. In essence, the non proliferation of this type of networks, as opposed to that of the wireless infrastructure networks such as wifi, is mainly caused by the inefficiency of routing protocols to get grasp of the underlying network dynamic topology in a timely and correct manner. The Optimized Link State Routing Protocol (OLSR [1]) stands out as the most reputed and adopted proactive routing protocol. OLSR does indeed fit some requirements of MANETs, and thrives well in reducing the signaling overhead. The key idea behind this reduction is the use of only some selected nodes called the Multi-Point Relays (MPRs) to broadcast by flooding the routing information (i.e. the Traffic Control (TC) messages) throughout the network. The crux of the operation of OLSR lies in its ability to provide, at the same time, a detailed and valid one and two hops neighborhoods by means of frequent exchange of Hello messages (this is often called the fisheye property of OLSR), and an acceptable correct direction towards the destination by means of the less frequent exchange of TC messages. However, several shortcomings are still affecting its operation and are certainly amenable to improvements. The responsiveness of OLSR to dynamic topology changes is its principal handicap. A link with a neighbor is declared only after a three way handshake necessitating three HELLO intervals. A HELLO declared link persists for a Hold time of 3 HELLO intervals if not updated and a TC declared link persists for a 3 TC intervals if not updated. Recall that a HELLO interval usually amounts to 2 to 3 seconds and that of a TC is usually fixed to 5 to 8 seconds. During a Hold Time, and as nodes are mobiles, a link may exceed the transmission range or run through obstructing obstacles and hence gets broken.

The contribution of this paper is four fold. Firstly, we propose a non-intrusive approach for the network cartography collection that uses the exact OLSR signaling. Secondly, we develop an enhanced version of OLSR, called the Cartography Enhanced OLSR (CE-OLSR) that uses the collected cartography to compute the routing table instead of the usual routing information collected and used by the seminal OLSR. Thirdly, we investigate, through extensive simulations, the performance betterments brought out by CE-OLSR in terms of a much greater throughput and a much lower average end to end delay. The routability of CE-OLSR (namely, the percentage of valid routes among the established routes at any instant is much greater than that of OLSR. Fourthly, we integrate into the simulated area some obstructing obstacles, and show that CE-OLSR thrives much better in avoiding such obstacles and maintaining appropriate valid routes.

The remainder of the paper is organized as follows. Section 2 presents some relevant related work. In section 3, we describe our CE-OLSR proposal. Section 4 is dedicated to the performance evaluation and the comparison between CEOLSR and the seminal OLSR. In Finally, we conclude the paper in section 5.

2. Related Work and Motivation

Routing protocols in multi-hop (MANETs) have attracted a great deal of attention and generated a host of proposals. The inherent characteristics of these networks make the routing process a rather difficult task. A viable routing proposal should appropriately take into account the scarcity of resources, the dynamics of the network and its components as well as the environment in which we are deploying such a network. These amounts respectively to the signaling overhead which needs to be reduced at maximum, the mobility model, and the propagation model. Of a particular interest is the routability of a routing protocol. Which is defined as the percentage of valid routes among those established in a given routing table. An established route is termed valid at a any given instant if it does really exists in the network. As a result, routability measures the efficiency and dependability of the routing protocol.

A large array of routing protocols has been proposed in the literature. Virtually all of these protocols fail to be efficient under frequent topology changes, and especially when some obstacles are considered within the network area. In this paper, we restrict our attention to proactive protocols.

The OLSR [1] protocol is currently the defacto proactive protocol in multi hop MANETs. The OLSR protocol introduced the concept of the Multi-Point Relay (MPR) in order to decrease the routing overhead. Despite the great success of OLSR in reducing the signaling overhead, its performance is highly affected by the network dynamics. This is mainly due to its slow responsiveness to topological changes as a link can persist for an entire Hold Time, a rather large period. Recall that in OLSR, a local link is declared between two neighbors after a three way handshake that requires a three Hello intervals each of 2 to 3 seconds. A remote link is declared through a TC message and can persist for a Hold Time of three TC intervals each of 5 to 8 seconds. It has been shown that reducing the TC period do not affect much the efficiency of OLSR, however reducing the Hello period has a positive effect [2]. However, reducing the Hello interval amounts to a direct increase in the signaling overhead which in turns affect the portion of used bandwidth otherwise left for the data traffic. Several extensions of OLSR were proposed in the literature such as F-OLSR [3] P-OLSR [4], and OLSRMORP [5]. All of these integrated a better predictability of the neighborhood of a node. The key idea behind P-OLSR and OLSR-MOPR consists in avoiding the use of intermediate nodes and MPRs that might be out of transmission range. The prediction of such an event is based on the position and velocity components (Vx,Vy,Vz) of neighboring nodes which are periodically announced within the HELLO messages. In P-OLSR, the neighbourhood prediction is used only locally to select stable MPRs, and TC messages are not extended. This makes distant nodes unaware of the predicted connectivities which may tacitely lead to incorrect routing decisions. Contrary to P-OLSR, OLSR-MOPR makes distant nodes aware of the locally predicted connectivities by integrating in their TC messages the values of the predicted GLS (Global Link Stability) of each published link. During the routing calculation step, OLSR-MOPR uses this information to select the most stable routes which are not necessarily the shortest.

On the other hand, stable routing has also emerged as a suitable concept to take account of the network dynamics and the mobility of nodes [6][7][8][9][10]. The main purpose here is to find routes that last better over time and sustain better the network dynamics until the next routing update. Even though, the stability criterion differs from an approach to another, the common goal of these approaches consists in switching data packets through better reliable links. Location based routing were also proposed to deal with the mobility of nodes [11][12][13][14][15][16]. The use of node positions instead of link states seems to be more effective in different ways. In geographic greedy approaches [17][18], the nodes do not need to store a complete view about the network connectivity. The knowledge of the position of the destination and that of some neighboring nodes is sufficient to reach the destination. When the routing process fails to find an appropriate route due to local maximum phenomenon (the current node has no neighbor closer to the destination then itself), a recovery mode is invoked in order to avoid obstacles or voids.

In wireless mobile ad hoc networks, an adequate compromise between route stability and its length in hops is essential for appropriately mitigating the impact of the network dynamics on the validity of established routes. In [19], we set up a common framework for the comparison between three families of proactive routing: the shortest path-based routing, the most stable path-based routing and the most stable constrained path routing. Besides, the network cartography (knowledge of the positions of the nodes) has been introduced in [20] to further tune proactive routing protocols and improve their efficiency. For instance, in prior works [20][21][22], we proposed the use of the network collected cartography to self-regulate the size of the routing period in proactive routing protocols. Such enhancements and autonomic management have permitted us to save valuable network resources while fulfilling high routing efficiency and achieving much better network performances.

In this paper, we propose a novel proactive routing protocol based on the exact signaling of OLSR but which computes the routing tables using the collected cartography of the network instead of the usual routing information of the seminal OLSR. We first propose an OLSR based gathering mechanism that we tuned appropriately to collect node positions and build a new data structure richer than the topology collected by OLSR, namely the network cartography. This cartography is then used jointly with the location of the different obstacles in order to retrieve an accurate topology view on which a stability based routing scheme with obstacle avoidance is performed. This amounts to our proposed routing protocol named Cartography Enhanced OLSR. Extensive simulations are then conducted to position CE-OLSR to OLSR.

3. The CE-OLSR Protocol

CE-OLSR is based on two mechanisms; namely a Cartography Gathering Scheme (the CE-OLSR-CGS) and a Stable Routing Approach (the CE-OLSR-SRA). The CE-OLSR-CGS in non-intrusive to the normal functioning of OLSR as it uses exactly the same signaling though it handles it in a more efficient way to incorporate a better responsiveness. The CEOLSR-SRA lies on the selection of somehow shorter links to allow more stability for the established paths.

The key ideas behind the CE-OLSR protocol stems from the inefficiencies of OLSR itself when applied to mobile multi-hop ad hoc networks as opposed to stationary MANETs. In stationary MANETs, OLSR behaves appropriately and delivers adequate performances; in particular it thrives well in reducing the signaling traffic. However, for dynamic MANETS, OLSR, as it is already the case of virtually all proposed proactive protocols, looses its efficiency and can hardly deliver sufficient performances as the dynamics get stronger. Here we purposely direct the attention to some inherent malfunctioning of OLSR that hinder its efficiency when applied to dynamic MANETs. First of all, the information carried by OLSR control messages, being either HELLO messages or TCs, are held during a relatively long period if not updated. The Hold Time is usually set equal to three times the periodicity of the corresponding control message. Recall that the periodicity of Hellos is usually fixed to 2 or 3 seconds and that of TC messages is of 5 to 15 seconds. Secondly, a link must undergo a three way handshaking before it can be forecasted within a TC message. In dynamic MANETs, nodes are mobile and the network connectivity is very dynamic. As such, the Hold Time and the three way handshaking have an obvious negative impact on the responsiveness of OLSR. Thirdly, OLSR is very sensitive to the loss of control packets especially the loss of TCs as they are the ones responsible to transport and inform the rest of the network about discovered local topologies. Fourthly, OLSR is inherently unable to distinguish between stale and fresh links as routing information is accumulated by a node regardless of its origins (the original Hello message from which the topological information emanated). Last but not least, the existence of obstacles within the network area worsens the observability and responsiveness of OLSR, as obstacles add a further degree to the dynamics of the network.

In the quest to resolve the above mentioned inefficiencies of OLSR, CE-OLSR bases its perception of the network using the cartography built by the CE-OLSR-CGS instead of the topology induced from the accumulated routing information. Since the network cartography is a much richer structure than a simple knowledge of the network connectivity, we can expect a significant improvement on the routing decisions. Recall that the proposed cartography collecting scheme uses, in a non-intrusive manner, the exact OLSR signaling traffic. As such, the CE-OLSR-CGS should take into account the aforementioned inefficiency of OLSR to be able to provide an adequate perception of the network and to attain a much better responsiveness. This will be exacerbated after the following subsection that presents the propagation model we adopt to handle obstacles.

3.1 Propagation Model with Obstacles

MANETs and their routing protocols are usually evaluated through simulations. However, the achieved performances could vary significantly with the modeled propagation environment. The existence of obstacles (i.e., buildings in a campus) within the network simulated area further affects the validity of established routes as nodes move around. In the OMNET++ simulator, which we shall be using to evaluate the performances of our proposal, the underlying basic propagation model used is the Free Space Propagation Model (FSPM). FSPM assumes a direct path between a transmitter t and a receiver r. The received power P_r at the receiver node depends on the transmitted power P_t, the wave length λ, the gain of the receiving antennae G_r, the gain of the transmitting antenna G_t, the distance d between the two communicating nodes, and a given system loss coefficient L. In FSPM, the received power at a distance d from the transmitting node is given by the following formula:

$$P_r(d) = \frac{P_t G_r G_t \lambda^2}{(4\pi d)^2 L} \tag{1}$$

In FSPM, the different parameters but d are kept constant throughout the simulation. This is indeed a deterministic simple model that has the benefit to ease the simulation overhead at the receiving node. Proper reception is achieved at the receiver side when P_r is greater than a fixed receiving threshold RX_{Thresh}. Alternatively, a proper reception is achieved whenever d is less than a Transmission range TX_{Range}. This TX_{Range} is in turn computed through equation (1) by fixing the P_r equal to RX_{Thresh}. In case P_r is less than the RX_{Thresh} but greater than the carrier sense threshold CS_{Thresh}, the receiving node drops the packet but the reception power still interferes with other received signals. Finally, transmissions with a P_r less than the CS_{Thresh} are simply dropped and do not disturb other signals received at this node.

Other more sophisticated propagation models have been recently integrated into the OMNET++ mobility framework simulation environment. In [23], the author proposed an urban propagation model including obstacles based on the Two Ray Ground (TWG) propagation model which behaves exactly as the FSPM up to a certain distance. Above this distance, the TRG is instead inversely proportional to λ^4. The received signal power is that given by the TRG if the signal does not cross any obstacle, otherwise it is totally obstructed. In [24], the authors proposed an OMNET++ model to take into account the shadowing effects when the signal crosses buildings. The shadowing model is a bit more advanced than the TRG as it includes two parameters representing respectively the number of times the line of sight between the communicating nodes intersects the obstacles and the width of the intersected buildings. In [25], the authors extended the OMNET++ Mobility Framework to support probabilistic propagation models and provided implementations for the Log-Normal-Shadowing, Nakagami, Rayleigh and the Rice wave propagation models.

For the purpose of this paper, we opted to extend the FSPM as it is the computationally most efficient propagation model and since our main objective is rather to investigate the performance of our CE-OLSR proposal against that of OLSR. We adopted the same approach used in [23] to account for entirely obstructing obstacles. The simulation area may contain a set of obstacles of whatever shape that totally hinder the propagation of signals. As a result, a node no longer has a circular coverage range. The received signal power is then given by equation (1) as long as the Line of Sight (LOS) propagation of the signal does not cross obstacles, otherwise it is put to null. The received signal power is then given by the following formula:

$$P_r(d) = \begin{cases} \dfrac{P_t G_r G_t \lambda^2}{(4\pi d)^2 L} & \text{no LOS crossing of obstacles} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Recall that P_t, λ, G_r, G_t, L, TX_{Range} and CS_{Thresh} are system parameters that do not change during the entire simulation.

3.2 CE-OLSR-CGS: The Cartography Gathering Scheme

Now we come to explain our proposed non-intrusive cartography scheme based on OLSR with some improvements to mitigate its aforementioned deficiencies. We assume that each node in the network knows its own position all the time. This assumption could be explained by the existence of several hardware or software positioning solutions such as the currently available low cost GPS receivers. Indeed, most of current smart phones come nowadays with a built in GPS. Recall that according to our adopted propagation model, a link between two nodes exists if and only if these two nodes are within transmission range and the LOS signal does not cross obstacles. Furthermore, we consider that obstacle shapes and positions are known to every node as a priori knowledge.

OLSR uses two kinds of control messages to discover the network topology. The neighborhood (1 and 2 hops) is discovered using HELLO messages. The rest of the network (nodes farther than 2-hops away) is discovered through TC messages. CE-OLSR-CGS uses the exact same signaling messages and traffic of OLSR. Nodes' positions are added using new fields in the generated control messages. In each generated HELLO message, the generating node includes its position as well as those of its neighbors. Each node selected as MPR includes the position of its MPR Selectors in its generated TC. It should be stressed here that although this is a very simple scheme to gather the network cartography information, it is able to deliver much better perception of the network. Indeed, this gathering scheme has the great ability of inferring the existence of several links that remain not established for OLSR in case of control message losses. In CE-OLSR-CGS many links can be inferred and established as by our propagation model a link exists if their two end nodes are within transmission range and the LOS propagation does not cross obstacles. This mitigates the negative impact of control messages losses of OLSR. In other words, CE-OLSR is more robust against the loss of control messages.

In the quest to overcome the slow responsiveness of OLSR caused by the required three way handshake and the Hold Time, each node include in its generated HELLO message not only the positions of its symmetric neighbors but also those of its asymmetric ones. Upon receiving a HELLO message, a node stores the cartographic information about asymmetric neighbors in a new dedicated structure.

Furthermore, recall that OLSR is unable to distinguish between newer and older (stale) topological information. Cartography information (i.e., positions) about a given node, say A, is advertised by several nodes through TC and Hello messages. The question naturally arises as to which one carries the most recent and therefore most accurate position of node A. The last received control message does not necessarily carry the most recent cartography of node A since we completely ignore from which Hello message this information was taken. We propose that each node (node A in this example) includes a sequence number when generating a Hello message. We propose to use the seminal sequence number of OLSR HELLO messages that could be attached to each position and disseminated in a HELLO or a TC message.

3.3 CE-OLSR-SRA: The Stability Routing Scheme

When the network is highly dynamic, the gathered routing information as well as parts of the collected cartography become stale rather rapidly. To mitigate such an impact, stable links, those which can last longer, should be selected to compose the different routes. Note here that a simplest solution might consist of increasing the frequency of control messages, especially the frequency of Hello messages. But this would necessarily increase the signaling overhead which would consume more of the network resources otherwise used to transport data traffic. This later solution is obviously not suitable as it leads to poor performances. Rather, we propose to take profit of the richness of the gathered cartography. First of all, the stability property we are adopting is based on the tacit fact that two moving nodes remain neighbors as long as their movement keeps them in transmission range (TX_{Range}) of each other. We enforce our stability routing scheme to select links respecting this stability property when computing the different routes. This stability property is achieved by willingly underestimating the actual gathered network connectivity. Let Stability Distance be a small fraction of the transmission range TX_{Range}, and let $STX_{Range} = TX_{Range} - StabilityDistance$ denotes the stability transmission range such that a link is termed stable, according to the gathered cartography by CE-OLSR-CGS, if its two end nodes are not farther than STX_{Range} and it does not cross obstacles. Notice that the more the *StabilityDistance* is increased the greater the routes' stability would be. However, increasing the Stability Distance also increases the number of hops to reach the destination using stable links. Moreover, increasing the Stability Distance enforces the underestimation of the actual network connectivity and may result in a disconnected graph especially for sparse networks. The Stability Distance should be tuned according to the density of the network, the degree of mobility of the nodes and the average number of additional hops we tolerate.

The CE-OLSR-SRA is based on the network cartography (nodes positions) gathered by the CE-OLSR-CGS, the network topography (the information about the obstacles positions and their shapes) and the stability property. The network topography can be readily provided through currently available street digital dynamic maps. First of all and locally at each node the CE-OLSR-SRA builds a Stable Connectivity Graph (SCG) from the gathered cartography. The SCG contains only the links that do not cross obstacles and that are within the stability transmission range STX_{Range}. All other links are just dropped. Then the CE-OLSR-SRA computes the routing table by running a shortest path algorithm, Dijkstra's algorithm for instance, to identify the gateway (the next hop node) for each destination node in the network.

4. Comparison of OLSR and CE-OLSR

4.1 Simulation Set Up

For both OLSR and CE-OLSR, we consider the following simulation parameters. We consider a mobile ad hoc network containing 100 mobile nodes (with initial random positions), and covering an area of 1000 *m* by 1000 *m*. The nodes mobility is driven by the Random Way Point model. The transmission range TX_{Range} is set to 250 *m*. The network capacity is fixed to 11 *Mbps*. The MAC is enabled to retransmit data packets 3 times before dropping them from transmission queues. We use a priority IP layer in which routing control messages are served before data packets. The priority IP queue can buffer up to 100 packets. In this queue 30% of its size is exclusively used by control messages and the remaining 70% are shared between data and control packets. The priority IP benefit is twofold. Firstly, it speeds up the dissemination of routing traffic which makes routes more consistent and closer to the real network topology. Secondly, it insures that packets are routed using the freshest topological information which saves a great amount of valuable network resources. The TC REDUNDANCY parameter is set to zero, hence MPRs publish only the links with their MPR selectors in the generated TC messages. In addition, we set the TC period to 8 *s* and the HELLO period to 2 *s*. The *Stability Distance* parameter of CE-OLSR is set to 50 *m*, that is one fifth of the transmission range TX_{Range}, hence providing STX_{Range} = 200 *m*.

In the conducted simulations invoking data traffic, 10 CBR (Constant Bit Rate) data streams are set up between 10 chosen nodes pairs. The data packets size is set to 1000 *Bytes*. The data streams are kept active during the whole simulation time. The nodes acting as stream servers and receivers are immobilized at the two extremities of the network area to preserve a path length ranging between 4 and 6 hops approximately.

The selected scenarios are run for a simulation time equal to 600 *s*. The first 200 *s* are pruned as representing a transient regime. The remaining 400 *s* simulation time are divided into 10 equal observation windows. Within each window of time, we apply an observation point each 0.5 *s*. Calculations of the different performance metrics are performed at each observation point. Represented results are averaged over these 10 periods. Simulation results concerning the validity of the routes (routability) are calculated at a stationary node positioned at the top left corner of the network area. Finally, two linear obstacles are added as shown in **Fig. 1**.

4.2 Simulation Results

Let us first evaluate the routability of CE-OLSR against that of OLSR using the above defined parameters and the network depicted in **Fig. 1** containing the two linear obstacles. The routability is defined as the percentage of valid routes among those established in the routing table of any given node. An established route between any source destination pair is termed valid at any given instant if it does really exist in the real network at that instant (this real network is provided by the simulator). The percentage of non established routes at any given node, and that do not exist in the real network, is also added to the routability.

Fig. 2 depicts the routability as a function of the node speed. We clearly observe that the validity of the routes provided by CE-OLSR outperforms by far that of OLSR as the speed of nodes gets higher.

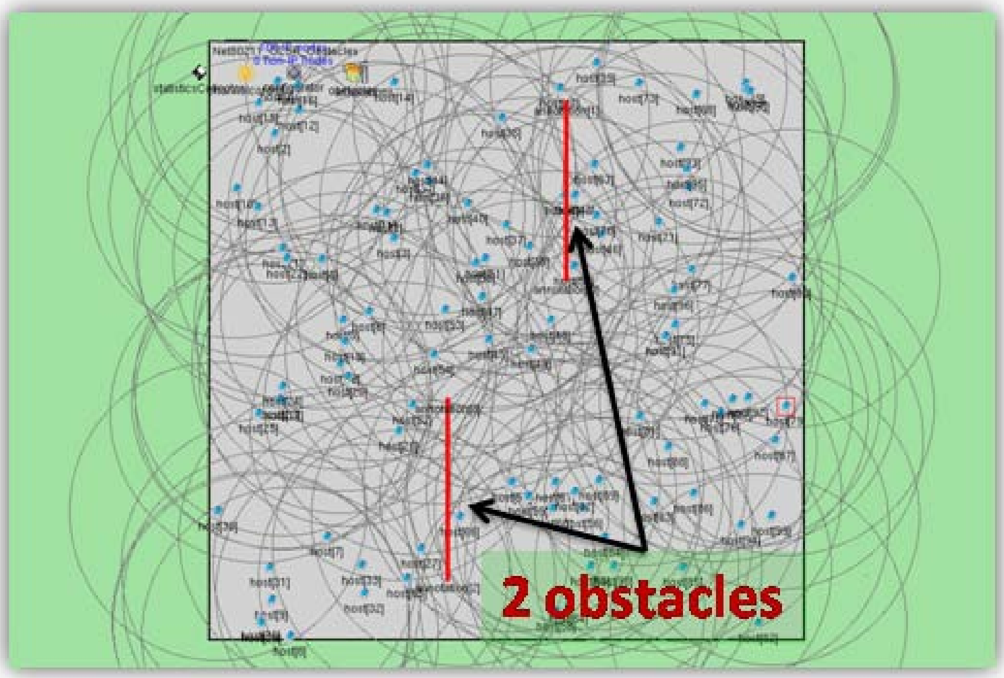

Fig. 1. A MANET with 2 linear obstacles

The routability of OLSR is severely affected by the increase of the node speed. CE-OLSR, however, portrays a strong robustness against the mobility of the nodes. At a low speed of 2 *m/s*, the validity of the routes of OLSR drops to approximately 78% while CE-OLSR keeps a high routability equals to 97.67%. At a speed equal to 10 *m/s*, the validity of the routes of OLSR drops to 40.54% while that of CE-OLSR remains above 92%. For a higher speed of 20 *m/s*, OLSR fails completely to track fast moving nodes. At such a speed, the routability of OLSR drops to 24.89% while that of CE-OLSR levels above 82%. These results clearly show that CE-OLSR is far more suitable for highly dynamic MANETs such as in logistics networks used in disaster prevention or in Vehicular Networks (VANET).

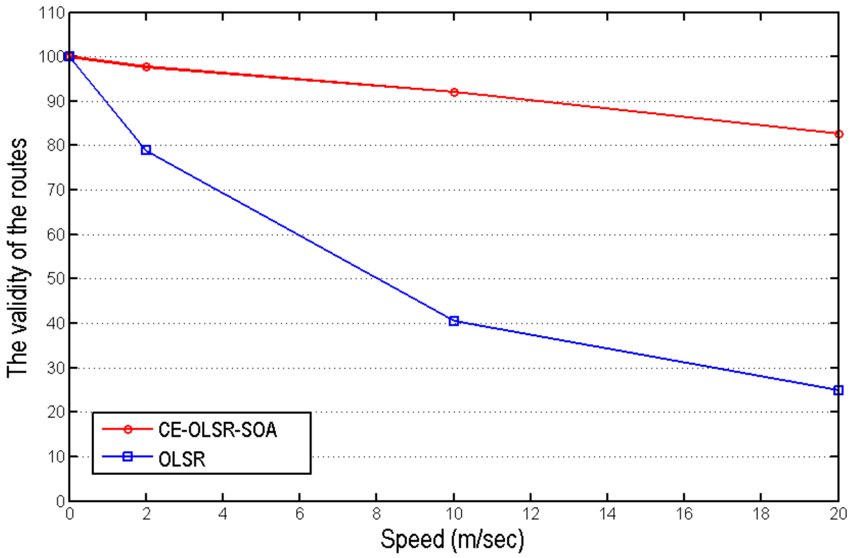

Fig. 2. The validity of the routes in OLSR and CE-OLSR in the presence of obstacles and for different speeds

The superiority of CE-OLSR stems from its ability to overcome the previously mentioned inherent limitations of OLSR (section 3) thanks to its Cartography Gathering Scheme (CGS) and its Stability Routing Approach (SRA).

The CGS makes the node aware of the freshest known cartographic information about each node in the network and therefore improves the responsiveness of CE-OLSR. In fact, with CE-OLSR, a node can distinguish between new and stale cartographic information whether it comes from HELLO or TC messages. This has been accomplished by joining the sequence number of the HELLO message from which the cartographic information was extracted. In addition, CE-OLSR uses the cartographic information about its 1-hop and 2-hops neighbors as soon as it is received without exerting a three way handshake. This fast adaptation of the 1-hop and 2-hops neighborhood has a beneficial effect on the routing efficiency. Indeed, new incoming neighbors are taken into account immediately upon receiving their HELLO messages. Moving nodes outside the neighborhood of a given node are also detected as soon as this node receives their cartographic information in a Hello from any surrounding node, and most importantly without waiting for the Hold Time. This fact is especially important when the departing node plays the role of the Next Hop in routes to some destinations. The prowess of our proposed cartography gathering scheme stems from its great ability to maintain a correct and up-to-date topological view about both of its 1-hop and 2-hops neighborhoods. As a result, CE-OLSR enhances the so called Fisheye property, hence yielding a correct and better selection of the Next Hops in routes towards destinations.

The SRA, on the other hand, provides more stability to established routes as it is applied rather on the underestimated topology inferred from the gathered cartography and the use of a restricted transmission range; namely the STX_{Range}. For instance, a Stability Distance of 50 *m* allows two neighboring nodes to withstand a mobility of 10 m/s in opposite directions (e.g., the worst scenario) for 2.5 *m/s* without affecting the route validity. Moreover, the SRA takes care of existing obstacles in the simulation area as it has a prior knowledge of the topography of the network terrain and a link is accounted for only if does not cross obstacles. At a first glance, the OLSR may be perceived as immune to obstacles as links should undergo a three way handshake before they can be accounted for. This is true in the context of a stationary network since the discovered links remain accessible during their lifetime. However for a dynamic MANET, the OLSR currently established links get broken upon crossing obstacles. In such a case, these broken links remain used until their expiration or until they are removed by subsequent updates. On the opposite, in CE-OLSR, a link that breaks down upon crossing an obstacle is avoided as soon as the new positions of its end nodes get known.

The great efficiency of CE-OLSR in terms of route validity let us expect its superiority against OLSR in terms of throughput and average end to end delay. The throughput represents the average number of received packets per second per data stream over the ten defined data streams. **Fig. 3**, **Fig. 4**, **Fig. 5** and **Fig. 6** portray the throughput achieved by OLSR and CE-OLSR as a function of the offered load per data stream and respectively for a node speed of 0 *m/s*, 2 *m/s*, 10 *m/s* and 20 *m/s*. In a stationary network, the case of a null node speed, OLSR slightly outperforms CE-OLSR as shown in **Fig. 3**. This is primarily due to the stability routing approach applied in CE-OLSR which increases slightly the length of the selected routes which in turn consumes some additional network resources. Recall that we have purposely fixed the sources (respectively the destinations) of our ten data stream at the left border of the network area (respectively at the right border of the network area). In this way, we forced the different routes of the data traffic to be within 4 to 6 hops. Conducted experiments showed indeed that the average route length selected by CE-OLSR is around one hop more than that selected by OLSR.

When mobility is invoked, the throughput achieved by CEOLSR substantially outperforms that of OLSR. As portrayed on **Fig. 4**, CE-OLSR throughput exceeds that of OLSR by approximately 25% for a data traffic load of ρ= 20 Pkts/sec. For higher node speeds, OLSR throughput is greatly impacted. For a node speed of 10 m/s, CE-OLSR delivers around three times more a throughput **Fig. 5** For a node speed of 20 *m/s*, OLSR fails almost completely to transport data packets, while CE-OLSR continues to deliver an adequate throughput, almost the double of what can OLSR deliver at half the node speed **Fig. 6**.

However, we notice that the throughput of both CE-OLSR and OLSR is affected by mobility, though at very different degrees. Nevertheless, CE-OLSR is much less impacted thanks to its fast adaptation and responsiveness to topological changes and also thanks to its stability routing approach. In addition, CE-OLSR has the tacit ability to rapidly prune links obstructed by obstacles thanks to its correct and up to date cartography and the knowledge of the network topography.

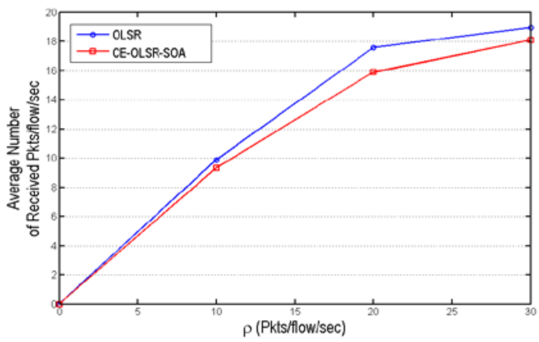

Fig. 3. Throughput of OLSR and CE-OLSR as a function of the offered traffic per data stream: Speed = 0 *m/s*

Now we turn to compare the average end to end delay achieved by both protocols. The end to end delay is a paramount requirement for interactive real time applications such as Voice over IP. In such applications, the network end to end delay should not exceed a certain bound; otherwise the application looses its comfort and adequacy. For a stationary network, both OLSR and CE-OLSR provide approximately the same performance up to a data load of 20 *Pkts/sec* as portrayed on **Fig. 7**. Beyond this data traffic load, OLSR starts delivering a lower average end to end delay than CE-OLSR. For a data traffic load of 30 *Pkts/sec* for instance, OLSR provides an average end to end delay of 0.086 *s* while that of OLSR reaches 0.64 *s*, still a very acceptable average delay. This as we previously mentioned, is caused by the increase of the route length which is due to the stability routing scheme applied in CE-OLSR.

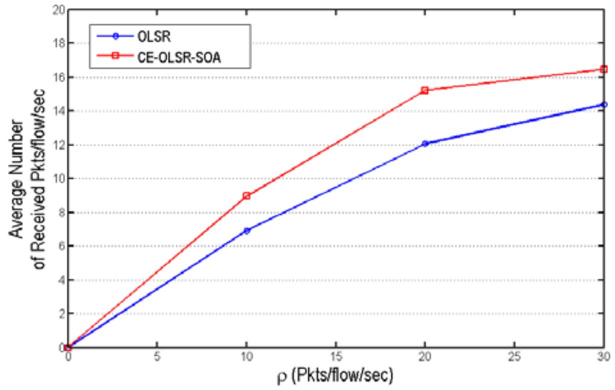

Fig. 4. Throughput of OLSR and CE-OLSR as a function of the offered traffic per data stream: Speed = 2 *m/s*

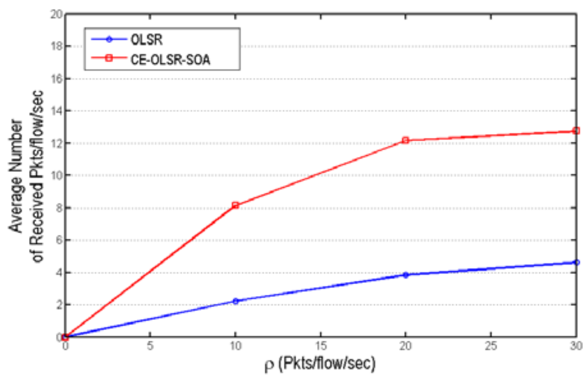

Fig. 5. Throughput of OLSR and CE-OLSR as a function of the offered traffic per data stream: Speed = 10 *m/s*

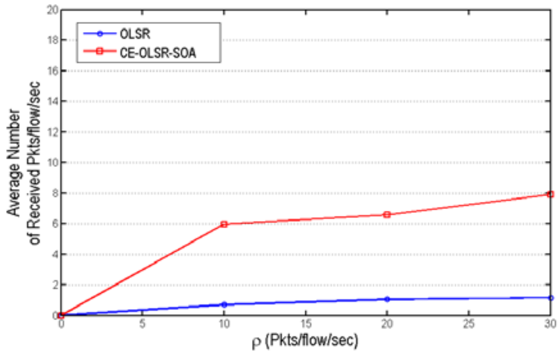

Fig. 6. Throughput of OLSR and CE-OLSR as a function of the offered traffic per data stream: Speed = 20 *m/s*

As soon as nodes start moving, the OLSR achieved average end to end delay starts exceeding significantly that of CE-OLSR. For instance, for the low speed of 2 *m/s* and a data load of 30 Pkts/sec, OLSR provides 0.28 s which is around the double of that delivered by CE-OLSR **Fig. 8**. At a speed of 10 *m/s* as portrayed on **Fig. 9**, CE-OLSR greatly outperforms OLSR. For instance at ρ = 30 Pkts/sec, CE-OLSR achieved an average delay around 0.46 s which is almost 4 times lower than that achieved by OLSR.

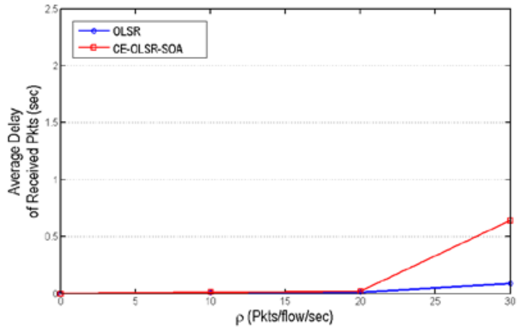

Fig. 7. Average end to end delay for OLSR and CE-OLSR as a function of the data load per stream: Speed = 0 *m/s*

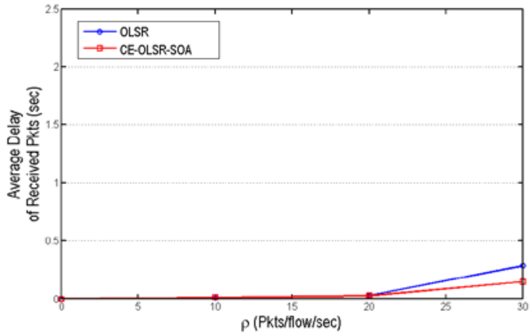

Fig. 8. Average end to end delay for OLSR and CE-OLSR as a function of the data load per stream: Speed = 2 m/s

As soon as nodes start moving, the OLSR achieved average end to end delay starts exceeding significantly that of CE-OLSR. For instance, for the low speed of 2 *m/s* and a data load of 30 Pkts/sec, OLSR provides 0.28 s which is around the double of that delivered by CE-OLSR **Fig. 8**. At a speed of 10 *m/s* and as portrayed on **Fig. 9**, CE-OLSR greatly outperforms OLSR. For instance at ρ = 30 Pkts/sec, CE-OLSR achieved an average delay around 0.46 s which is almost 4 times lower than that achieved by OLSR.

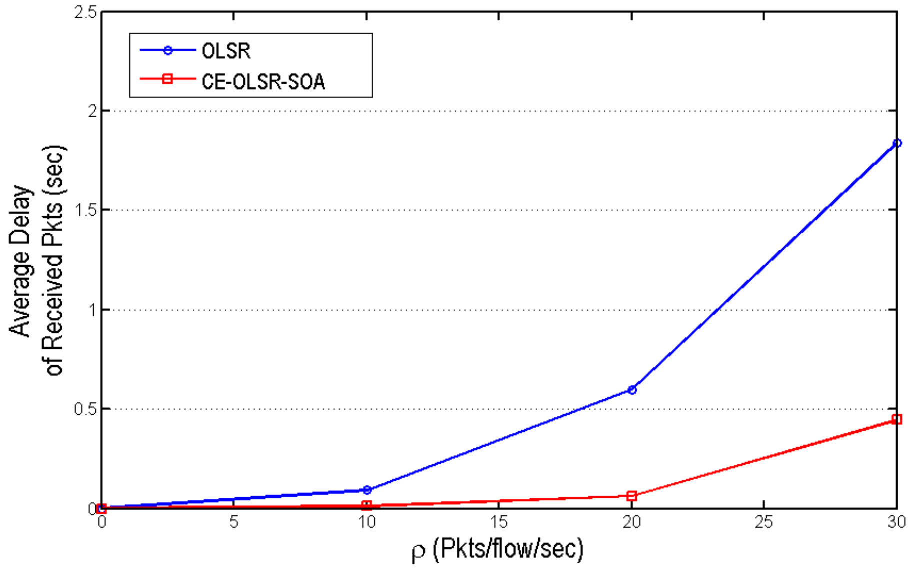

Fig. 9. Average end to end delay for OLSR and CE-OLSR as a function of the data load per stream: Speed = 10 m/s

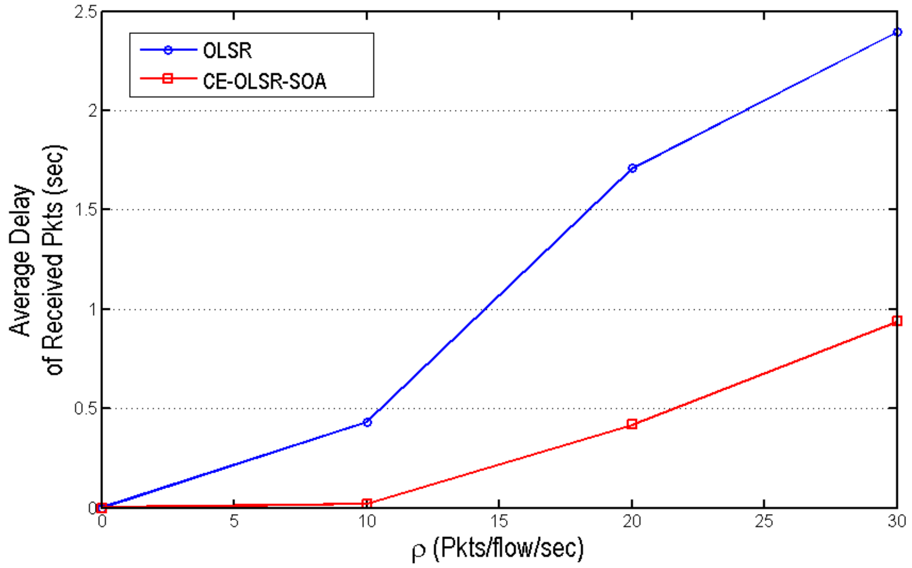

Fig. 10. Average end to end delay for OLSR and CE-OLSR as a function of the data load per stream: Speed = 20 m/s

For the high speed of 20 *m/s* as portrayed on **Fig. 10**, CE-OLSR achieved an average delay of 0.93 s at a load of ρ = 30 Pkts/sec, which is a tolerable average delay for certain real time applications working at this high data load. For a data traffic load of ρ = 20 Pkts/sec, CE-OLSR provides a very suitable average delay just under the 0.5 s. On the other hand, OLSR achieved intolerable delays for real time applications for medium to high workloads. For ρ = 20 Pkts/sec, OLSR attains an average delay more than 1.7 s and for a work load of ρ=30 Pkts/sec, it attains more than 2.3 s.

5. Conclusion

In this work, we first identified the inherent operational shortages impacting the efficiency of OLSR when applied to mobile multi-hop ad hoc networks. Then, we proposed a novel routing protocol that is based on a cartography gathering scheme, the CE-OSLR-CGS, and a stability routing approach, the CE-OLSR-SRA. The cartography gathering scheme is a non intrusive scheme that uses the exact OLSR signaling traffic but in a more enhanced manner. The built cartography is kept up to date to provide a valid view of the real cartography of the network. Based on this cartography, CE-OLSR acquired much better responsiveness than OLSR. The stability routing scheme performs the routing computations on a reduced connectivity graph that is inferred from the cartography collected by the CE-OSLR-CGS and a lower transmission range. The lower transmission range, called the STX_{Range}, underestimates the actual gathered cartography to allow more stability for the chosen links composing the different established routes. Moreover, the CE-OLSR-SRA only includes, in the reduced connectivity graph, links that do not cross obstacles. As such and owing to the efficient responsiveness, CE-OLSR is able to avoid obstacles and rapidly recovers obstructed links.
Conducted simulations showed the great efficiency attained by our proposal in terms of a very high routability, a much greater throughput and a much lower end to end average packet delay. The superiority of CE-OLSR in tracking the network dynamics especially around a node neighborhood increases significantly the validity of the routes that are showed to exceed 82% for the high node speed of 20 *m/s*. The validity of the routes in OLSR showed a significant degradation with the increase of the node speed. OLSR route validity can barely attain the 25% for that speed of 20 *m/s*. For dynamic networks, CE-OLSR achieves a throughput that attains more than 600% of that achieved by OLSR for certain node speeds.

Conducted simulations also showed that the average end to end delay of CE-OLSR is many times smaller than that of OLSR for certain node speeds. This makes of CE-OLSR a viable candidate for multi hop MANETs transporting real time data traffic.

The *Stability Distance* is a key parameter of the CE-OLSRSRA. This parameter is normally a function of the network dynamics, the network density and the tolerated increase in the average path length among others. The *Stability Distance* parameter has a direct impact on the stability of the established routes but it also affects the network resource utilization, the network performance and the network connectivity view. We used a rule of thumb to fix the value of this parameter. Currently, we are investigating ways to determine its appropriate values in an autonomic, local and dynamic manner.

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Dr. Abdelfettah Belghith received his Master of Science and his PhD degrees in computer science from the University of California at Los Angeles (UCLA) respectively in 1982 and 1987. He is since 1992 a full Professor at the National School of Computer Sciences (ENSI), University of Manouba, Tunisia. His research interests include computer networks, wireless networks, multimedia Internet, mobile computing, distributed algorithms, simulation and performance evaluation. He runs several research projects in cooperation with other universities, research laboratories and research institutions. He is currently the Director of ENSI, the Director of the Doctoral School (Graduate School) STICODE of the University of Manouba, the responsible of the Network and Distributed Systems Master degree and the head of the HANA Research Group (www.hanalab.org) at the National School of Computer Sciences.

Mohamed Belhassen is currently a Teaching Assistant at the Higher Institute of Computer Science, Medenine, University of Gabes. He received his Master degree in computer science from the Faculty of Science at the University of Monastir in 2008. He is currently pursuing his Ph.D. degree in Vehicular Ad hoc Networks (VANET) at the National School of Computer Sciences (ENSI), the University of Mannouba. His research interests focus particularly on location and geographic routing in vehicular mobile ad hoc networks.