



A link-state QoS routing protocol based on link stability for Mobile Ad hoc Networks

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ABSTRACT

In this paper, we propose a new mechanism to establish stable and sustainable paths between all pairs of nodes in a Mobile Ad hoc Network. In this mechanism, we use a stability function as the main path selection criterion based on the calculation of the mobility degree of a node relative to its neighbor. We applied this mechanism on the OLSR protocol (Optimized Link State Routing Protocol) to elect stable and sustainable MPR (Multipoint relays) nodes and topology. This mechanism significantly minimizes the recalculation of MPR and the routing tables recalculation process. Moreover, it guarantees other QoS (Quality of Service) metrics such as the packet loss and the response time. The simulation results show the effectiveness of our mechanism and encourage further investigations to extend it in order to guarantee other QoS requirements.

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1. Introduction

Mobile Ad hoc Networks (MANETs) are a class of infrastructure less networks, which are formed by a number of autonomous wireless and mobile nodes (Corson and Macker, 1999). The inherent characteristics of such networks make the support of multimedia applications very challenging. In fact, the nodes' mobility and the scarce resources directly impact the deliverance conditions of packets, which also depend on the selected paths' quality (Gangwar, 2012). The classical routing strategies, such as AODV (Ad hoc On-demand Distance Vector) (Perkins et al., 2003), DSR (Dynamic Source Routing) (Johnson et al., 2007) and OLSR (Clausen and Jacquet, 2003), mainly focus on minimizing the number of hops of the provided paths. This criterion is clearly inefficient to guarantee the services' quality. Indeed, minimizing the number of hops does not guarantee the quality of the selected links. Otherwise, these protocols select, by default, the farthest nodes to reach the destination with the minimum number of hops. In this way, many QoS-enabled routing protocols were proposed. Some of these protocols attempt to provide the best paths in terms of a selected metric (distance, signal power, etc) or a combination of metrics (example: speed and angle of movement of nodes) (Chlamtac et al., 2003). Some other approaches focus on resources' reservation (Chlamtac et al., 2003). In these two classes of protocols, the nodes

mobility is not really considered. In fact, the nodes' mobility may clearly affect both the quality of the selected paths and their durability. Thus, the route selection process should also consider the link stability criterion (i.e. links' durability), which allows to maintain the characteristics of the selected paths (Zhu et al., 2006).

To address the stability of links, the routing decision is usually based on the signal strength or the distance between the nodes. Most of the existing protocols consider the signal strength/distance to guarantee the link stability during a certain period of time. However, these approaches lead to the selection of the nearest nodes which increase the hops' count. This may clearly degrade the QoS of the supported applications and affect the performance of the network (Lal et al., 2011).

Analyzing the existing protocols allows us to classify the earlier works focused on the routing protocol based on the link stability in two classes: based on the distance and based on the mobility of nodes. The major of these protocols assesses the link stability based on the geographical positions of the nodes, provided by the GPS (Global Positioning System), or proposes the complicated probabilistic methods to estimate the reliable link lifetime. The routing mechanism based on the link stability, which minimizes the frequent path disconnections and guarantees other QoS requirement such as the packet delivery ratio, constitutes the first motivation of this work. So, in this paper, we present a new probability-based mechanism enabling an accurate estimation of the links' stability. We consider the signal strength variation as a main indicator of the nodes' mobility. The use of such metric allows to effectively select the best paths in terms of stability. In opposition to the existing approaches, it allows, at the same

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time, to optimize the hops' number by selecting nodes based on their mobility and not on the signal strength or distance. Since the proposed technique mainly depends on periodically exchanged packets, we propose to apply it as an extension of a proactive protocol. The OLSR protocol is considered in this paper. Thus, we propose the modification of two mechanisms of the classical OLSR protocol: the MPR selection and the topology discovery.

The rest of the paper is organized as follows: Section 2 is about the related work. So, we select and summarize several studies on the same issue and we will classify them to statute our work. The proposed mechanism to estimate the link stability is detailed in Section 3 and we describe the integration of this mechanism into the OLSR protocol in Section 4. Section 5 analyses the performance of the proposed approach and we conclude our work in Section 6.

2. Related work

In this section, we present some routing protocols based on the link stability in wireless Ad hoc networks. First, we classify these protocols according to two metrics: the distance and the mobility of nodes. Distance-based protocols try to minimize the distance between a node and its successor in the established path. In the second class, protocols try to quantify and assess the links between nodes of the network based on their mobility. This class regroups two types of protocols: class of protocols based on the parameters of nodes' mobility (speed, direction of movement, coordinates of nodes, etc) and class of protocols based on the degree of mobility or the probability that the mobile node remains a neighbor of another node (probabilistic methods).

2.1. Distance based protocols

We present in this section an overview of works that summarizes the class of distance-based protocols. The distance between nodes is calculated generally using localization systems or based on the signal-power of messages exchanged between nodes. In Wang San et al. (2005), authors proposed the protocol SSOD (Signal Strength based On-Demand). This protocol installs paths according to the signal strength metric. After receiving several answer messages by the source, it selects the path that its minimum value of signal powers is the largest in comparison with the minimum values of the other paths. The path, that has the sum of the links' stability parameters greater than the sums of the other paths, will be elected as the most stable in the case of multiple paths. TBP-SE (Ticket-Based Probing with Stability Estimation) proposed in Zhu et al. (2006) is an amelioration of Ticket-Based Probing protocol (TBP) (Chen and Nahrstedt, 1999). This last, installs paths based on QoS requirements but without considering their stability and their durability. For this, the authors of TBP-SE have added to this protocol another metric for stable and durable paths selection. This metric of link stability, based on the distance between nodes, is calculated by the information provided by the GPS or the signal quality. In Alicia et al. (2006), the authors proposed an approach based on the signal power to evaluate the links' stability. For this, the authors propose two criteria: the first selects the path that has the minimum signal power greater than the minimum signal power of the other paths, and the second installs paths depending on the number of hops and checks the first metric. Nityananda Sarma and Sukumar Nandi have proposed a protocol based on the signal strength to estimate the stability of the link (Sarma and Nandi, 2006). The authors consider the link stability with other QoS metrics to obtain a QoS routing protocol based on the link stability. The path that has the largest product of links' stability values compared to the other paths will be elected as the most stable.

2.2. Protocols based on the mobility of nodes

Several protocols consider the mobility of nodes to estimate the stability value of links such as the direction of movement of nodes, their speed and their probability of remaining in the vicinity for a long period. Authors in Tarneg et al. (2006) proposed a method to calculate the probability that a node receives a signal from its neighbor with a power higher than a predefined threshold. The information of mobility of nodes is received by the localization system (GPS). This protocol is similar to AODV in its phases of installation and maintenance of paths except the path selection metric which is based on the link stability instead of the number of hops. In Li et al. (2010), authors propose a protocol where the choice of the path is done based on two metrics: the residual energy and the mobility of nodes. For this, they have proposed a formula to calculate the weighted sum of the two metrics. The authors calculate the residual energy metric as the remaining energy of a node divided by the rate of the traffic that passes through this node. The second metric is calculated as the difference of the number of the node's neighbors in time T and time $T-\delta(T)$ divided by the number of its neighbors in time T . Authors of the protocol LSEA (Link Stability and Energy Aware) (Hamad et al., 2011) proposed some changes in the protocol AODV to address the path durability and the amount of residual energy constraints. These changes were made on the propagation of the RREQ (Route Request) packets especially for nodes that have a better satisfaction of both the constraints. To evaluate the link stability, they used the method proposed in Su et al. (2001) which is based on the GPS system. Another link stability based protocol is proposed in Lian et al. (2008) where the objective is to ensure, first, a sufficient bandwidth, and second, the delay, an acceptable jitter and a long lifetime of the selected paths. The lifetime of paths is calculated as a function of vectors of speeds and positions of the nodes received by the GPS system. Three schemes have been proposed in Al-Akaidi and Alchaita (2007) to establish paths toward the geographical direction of the destination node using the Localization System or the direction sensors. In the first scheme, the diffusion of the RREQ messages is intended only to nodes that are in the same direction as the destination node. In the second scheme, the zone propagation of the RREQ packets is divided into eight zones of 45° where the source node sends requests to one node in each zone. In the last scheme, the RREQ messages are sent only to the geographical direction of the destination node. Another protocol called SWOP (Stable Weight-based On-demand routing Protocol) (Wang et al., 2007) was proposed. This protocol uses three criteria to select a path: the expiration time of path, the number of errors and the number of hops. For this, a function that calculates the weighted sum of these three factors has been proposed. The synchronization of nodes and the parameters of motion are obtained by a localization system such as GPS. The expiration time of the link is calculated as a function of the speed, the angle of motion and the coordinates of the nodes. Authors in De Couto et al. (2005) proposed a well-known metric for electing the stable node by estimating the number of transmissions required to successfully send a packet over that link called: ETX (Expected Transmission Count). The ETX for a path is the sum of the ETX metrics for each link on this path. This metric is proposed to be incorporated into OLSRv2 (Rogge et al., 2010). LLMR (Learning automata-based Link stability Multicast Routing algorithm) is a new algorithm proposed in Akbari Torkestani and Meybodi (2011) and based on a stochastic Steiner tree algorithm for constructing the multicast route in Ad hoc networks. In this algorithm, a learning automata is proposed for solving the proxy Steiner tree problem, where the duration of a communication link is defined as the random weight of its corresponding graph edge. The duration of the communication

link, which is utilized as a stability metric in this algorithm, is calculated based on the velocity and the coordinates of nodes which are provided by the GPS. In Song et al. (2012), authors proposed a new method to assess the quality of the link in terms of link duration. For this, they adopt a variable sized sampling window and propose a probabilistic method, based on the Markov chain, to estimate the link transition rates (the probability that a link changes the state from the connected to unconnected state and vice versa). To show the effectiveness of this method, authors proposed a routing method which adjusts its operating mode (i.e. OLSR, AODV and ZRP (Zone Routing Protocol)) based on the estimated link stability (stable, unstable or relatively stable). Guo et al. (2011) proposed an enhancement of the OLSR protocol, which considers three objectives: minimizing average end-to-end delay, maximizing the network energy lifetime, and maximizing the packet delivery ratio. To achieve this goal, they developed three metrics: mean queuing delay on each node, energy cost on each node, and the link stability on each link. The metric of the link stability is estimated using a heuristic of the pattern of the link lifetime variation derived from the normal-like distributions of the link lifetimes.

The protocols mentioned above guarantee a stable path for communicating nodes, but present certain problems. In certain cases, the use of the localization system is not always possible especially in the presence of obstacles or the absence of interface card with the localization system in some nodes. Distance-based protocols minimize the distance between two adjacent nodes in the established path which consequently generates a large number of hops. Although, these protocols provide stability and longevity of paths, they degrade the network performances (congestion, collision, high transfer delay, etc). For the protocols based on the mobility of nodes, the evaluation of links according to the mobility of a node relative to all its neighbor does not reflect in all cases the link state between all pairs of neighboring nodes. On the other hand, some protocols propose complicated methods to process which take more time and consume more energy. Other works use dissemination of periodic Hello messages to evaluate the link stability in reactive protocols.

In our contribution, we propose a new function to calculate the link stability by taking into account all the mentioned problems. This function is based on the calculation of the probability that a link will remain active for a long time. Our method, simple in its implementation, measures the link stability values depending on the variance of the signal power of the messages exchanged between pairs of the neighbor nodes. To demonstrate the effectiveness of our contribution, we introduced this solution into a proactive protocol which is OLSR. The implementation has focused on the famous concepts of OLSR: the selection of the MPR and the topology discovery.

3. Our proposed mechanism for searching more stable routes in the network

As a part of improving the quality of service in MANETs and based on the study of stability of nodes, we propose a new metric based on the two concepts: the Stability of NoDes (SND) and the Fidelity of NoDes (FND). Hence, we define and we discuss both of these concepts. Notice that SND and FND are used to improve the MPR selection algorithm in terms of stability degree of the chosen MPR nodes. Further, the topology discovery and paths selection between all pairs of nodes are based on the SND concept.

3.1. Stability of NoDes (SND)

In Ad hoc Networks, there is no absolutely stable nodes (all the nodes can move randomly and at any time). The notion of stability

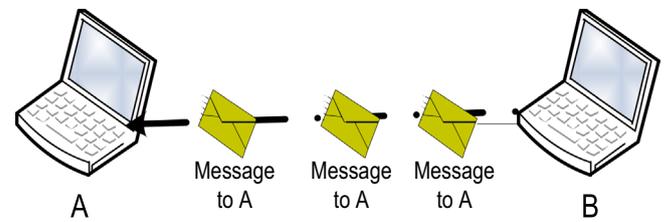


Fig. 1. Archiving process of received messages for calculating SND.

that we present in this paper is based on statistics collected by a node on its neighbor to estimate the durability of the connection. In Fig. 1, the node A, and after the reception of messages received from B, calculates the stability of the link joined with B.

To estimate this stability, we have proposed a function based on Bienaymé–Chebyshev inequality (Csizsar and F-Mori, 2009).

3.1.1. Bienaymé–Chebyshev inequality

In probability theory, Bienaymé–Chebyshev inequality guarantees that in any data sample or probability distribution: whatever be the discrete variable X , the strictly positive expectation $E(X)$, and the variance $V(X)$ we have the following inequality:

$$P\{|X-E(X)| < \varepsilon\} \geq 1 - \frac{\text{var}(X)}{\varepsilon^2}$$

The probability

$$P\{|X-E(X)| < \varepsilon\}$$

is always true if the variance tends to zero

$$1 - \frac{\text{var}(X)}{\varepsilon^2} \text{ tends to } 1 \Rightarrow V(X) \text{ tends to } 0$$

This also reflects the probability that the value of the random variable X is always close or equal to its expectation (little change in the future):

$$P\{|X-E(X)| < \varepsilon\} \text{ little change in the future}$$

By definition

$$V(X) = E(X^2) - E(X)^2$$

and

$$E(X) = \sum_i \frac{X_i}{n}$$

$$V(X) = \left(\sum_i \frac{X_i^2}{n} \right) - \left(\sum_i \frac{X_i}{n} \right)^2 \quad (1)$$

3.1.2. Stability function of a node

In our proposal (based on Bienaymé–Chebyshev inequality) instead of taking the X_i as the actual positions of the nodes (absence of this information in Ad hoc networks without the localization systems), we will take the values of the received signal power from a neighboring node in different intervals of time. Otherwise (see Fig. 1), the link between the node B and the node A is stable if the values of the signal power are very close to their expected value. In a particular case, if the mathematical variance of these signal power values is equal to zero, we can say that the node B is strictly stable with the node A. The function of stability that we propose consists of calculating the stability of a neighbor B by a node A (Fig. 1) as follows:

$$SND_{AB} = V(X_B) \quad (2)$$

According to (1) and (2)

$$SND_{AB} = \left(\sum_i \frac{X_{Bi}^2}{n} \right) - \left(\sum_i \frac{X_{Bi}}{n} \right)^2$$

$$SND_{AB} = \left(\sum_i \frac{Value_signal_{Bi}^2}{n} \right) - \left(\sum_i \frac{Value_signal_{Bi}}{n} \right)^2$$

(a) *Illustrative example:* Let B1, B2, B3, B4, B5 be five neighboring nodes of a node A, and P1, P2, P3, P4, P5 be the corresponding measured values of the signal power of the received messages from each neighbor (the power values shown in the table are chosen for ease of explanation and do not reflect the values of the real power). After receiving a message from each neighbor Bi, the node A calculates $V(P_i)$ and accordingly selects the more stable neighbor. As shown in Table 1, among the four nearest neighbors (B1, B2, B3 and B4), the node B1 is the most stable in comparison with the others. If two neighbors have the same value $V(P)$ (as is the case for B3 and B4), the neighbor that has the highest signal power value of the last exchanged message will be considered more stable (i.e. B3). On the other hand, B5 is totally stable with the node A.

3.2. Fidelity of NoDe (FND)

The graph in Fig. 2 represents an Ad hoc network where the weights of edges are the SND and the weights of vertices are the FND. In the case of OLSR, for example, the FND is the degree of reachability. In the case of our proposal, it is the degree of reachability with only the stable nodes. For example, in Fig. 2, the node 8 has two links with two nodes: the node 3 with SND equals to 2.3 and the node 2 with SND equals to 1.6. The node 8 chooses the node 2 as the most stable (minimum SND) where it

Table 1
Node stability computation.

Node	P1	P2	P3	P4	P5	$V(P_i)$
B1	2.152	2.101	2.356	2.370	2.220	0.01156416
B2	1.206	0.152	0.116	0.256	0.114	0.17789216
B3	3.007	3.100	3.102	3.750	3.700	0.10449936
B4	3.700	3.750	3.102	3.100	3.007	0.10449936
B5	3	3	3	3	3	0

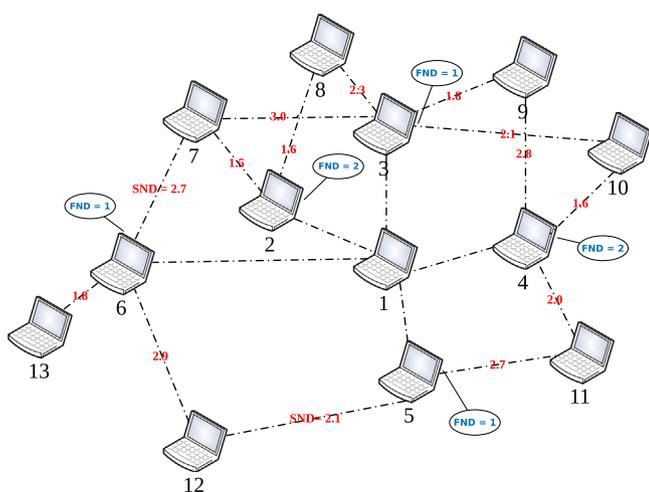


Fig. 2. Illustrative example of the Fidelity notion.

gives it a token. Similarly, the node 7 gives its token to the node 2. We conclude that the fidelity FND of the node 2 is equal to 2.

4. Integrating the SND and the FND mechanisms in OLSR

We opt to integrate the SND and FND mechanisms in a proactive and standardized protocol. Then, we choose the OLSR protocol. The main reason for choosing OLSR is the periodic distribution of the control messages to calculate the regular SND and FND which is not tolerated in the reactive protocols. OLSR is based on two principles for the collection of information on the global state of the network: the mechanism of MPR and that of TC (Topology Control) messages. In our proposal, we integrate the SND and FND mechanisms in both concepts of the OLSR protocol: the MPR calculation and the topology discovery. This solution will allow to create a more stable network topology compared to the standard OLSR. The new protocol arising from this integration is called ST_OLSR (STable OLSR).

4.1. Integration of the stability mechanism in the MPR calculation

OLSR is a proactive protocol that minimizes and optimizes the flooding of control messages in the network. For this, the authors of this protocol have proposed to use the concept of MPR to minimize the exchange of control messages just between these MPR nodes. This concept (of multipoint relays) was introduced by the standard HyperLan 1 (ETSI, 1996) project Hypercom/INRIA. A node in the network must route its data to a remote destination (over two hops) through only MPR nodes. When a node receives a message for the first time, it retransmits this message if it is a multipoint relay of the node that sent the message. Recursively and by repeating this process, the message reaches the entire network (Clausen and Jacquet, 2003). The following figure shows an example of diffusion using multipoint relays.

4.1.1. Standard algorithm for MPR set calculation

Authors of the OLSR protocol proposed in Clausen and Jacquet (2003) a heuristic method to elect MPR nodes where they try to minimize their maximum number in the network. In this method, a recursive algorithm is applied in each node to elect its MPR in the one-hop neighborhood. This algorithm selects a neighbor node as MPR if the link to this neighbor is symmetric and this neighbor covers the maximum number of two-hop neighbors of the node (degree of reachability). The MPR node selected and the two-hop nodes covered by this MPR will not be considered in the next iteration of the algorithm. This algorithm is repeated until all the two-hop neighbors will be covered by the selected MPR nodes. Authors in Qayyum et al. (2002) showed that the calculation of a minimum set of multipoint relays using this algorithm is a NPcomplete problem.

4.1.2. MPR set calculation algorithm in ST_OLSR

The above mentioned mechanism of MPR set calculation (MPR in standard OLSR) is based only on the degree of reachability. So, this mechanism tries only to minimize the flooding in the network by using a proactive protocol. Our proposal is still based on this principle but it selects the set of more stable MPRs in order to keep the network topology stable as long as possible. This stability leads to a significant reduction of the MPR computation time, the frequent disconnection of paths and the number of recalculated routing tables. Therefore, we present the new format of Hello messages as well as our proposed algorithm for the MPR calculation (Fig. 3).

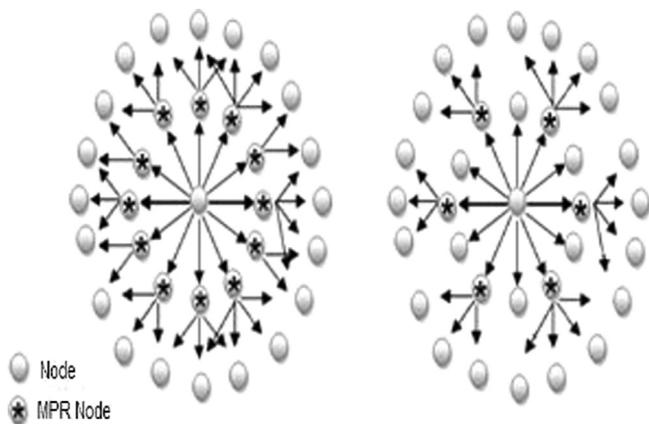


Fig. 3. Diffusion of broadcast message using flooding and multipoint relays.

0					1					2					3																																		
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
Reserved										Htime					Willingness																																		
Link Code					Reserved					Link message size																																							
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Fig. 4. New format of Hello message in ST_OLSR.

(a) *Format of the Hello message:* For our proposal and with respect to the standard Hello message, we introduce the value of stability SND for each neighbor node as shown in Fig. 4.

(b) *New MPR selection algorithm:* The election of MPR in our proposal is based on the FND concept. For this, we have introduced changes to the algorithm described in Section 4.1.1 for the election of stable and durable MPR. In our algorithm, a neighbor node is selected as MPR if the link to this neighbor is symmetric and it has the greatest FND value compared to the others. In the case of equal FND values for several nodes, the node which has the largest degree of reachability (which covers a large number of two-hops neighbors) will be elected as MPR. The following algorithm (Algorithm 1) describes the process of stable MPR election. In this algorithm, we note that:

- $N(x)$ is the set of direct neighbors of x .
- $N^2(x)$ is the set of neighbors of the second level.
- $MPRset(x)$ is the set of multi-point relays of x .

Algorithm 1. New MPR selection algorithm.

1. Start with an empty multipoint relay set.
2. Calculate the degree $D(y)$ of each node in $N(x)$.
3. Calculate the fidelity $F(y)$ of each node in $N(x)$. $F(y)$ is the number of the obtained tokens.
4. Select the nodes of the neighbors set $N(x)$, which are the only connected with a neighbor of the second level. Add these selected nodes of $N(x)$ for all $MPRset(x)$ and remove all nodes of the second level covered by them of all $N^2(x)$.
5. While ($N^2(x)$ is not empty) Do
 - {
 - (a) Calculate reachability $R(y)$ of each node in $N(x)$.
 - (b) Add the node (y) of $N(x)$ with $F(y)$ maximum to $MPRset(x)$.
 - }

If the values are the same, take the node with the highest degree of reachability $R(y)$.
 If they are equal then we take the node with the maximum degree $D(y)$.
 Remove all nodes of the second level covered by this node in the set $N^2(x)$.

}

4.2. Integration of the mechanism of stability in the topology discovery and the path selection

OLSR is a proactive protocol based on the MPR mechanism. The main function of MPR is relaying the messages between nodes in the network and selecting shortest path to the destination node. For this reason, the topology discovery in OLSR is only between MPR nodes. Each MPR node regularly broadcasts TC messages to inform the network of its list (MPR selectorset) of nodes which has elected it as MPR. Only MPR nodes are involved in the processing and the redistribution of the TC messages. These TC messages help in the creation and the maintenance of the routing tables in the MPR nodes. We have presented a modification of the standard algorithm of MPR election for the selection of stable and durable MPR. This change certainly influences on the topology discovery which will be more stable. To ensure more stability in the selected paths, we have introduced the concept of SND in the topology discovery and the calculation of the routing tables. This information of stability (SND) must be carried in the TC messages to reach other MPR nodes. In what follows, the changes on: the TC messages, the topology discovery and the calculation algorithm of routing tables will be presented.

4.2.1. Modification of TC message format

The main goal of our work is to calculate stable MPR and maintain routes based on the stability values instead of the hop count. For these reasons, the exchanged messages are modified to support the information of the stability values. Figures 4 and 5 show the change made on the Hello and TC packets.

4.2.2. Topology discovery

Each MPR node in OLSR maintains a topology table to record the global state of the network. This table is used for the calculation of routes between all pairs of nodes. Each entry in the topology table is represented by the tuple ($T_dest_addr, T_last_addr, T_seq, T_time$) where the definition of each field (Clausen and Jacquet, 2003) is as follows:

T_dest_addr, T_last_addr : T_dest_addr is the main address of a node, which may be reached in one hop from the node with the main address T_last_addr .

T_seq : is a sequence number.

T_time : specifies the time at which this tuple expires and MUST be removed.

0					1					2					3																								
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
ANSN										Reserved																													
Advertised Neighbor Main Address																																							
SND																																							
Advertised Neighbor Main Address																																							
SND																																							
.....																																							
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Fig. 5. New format of TC message in ST_OLSR.

After receiving the TC messages, an MPR node proceeds for the establishment or the update of its topology table. We then present our modification to the algorithm of creating and updating the topology table of the standard OLSR (see Algorithm 3) which consists of the recording of the SND stability value of each link.

Algorithm 2. Algorithm of the creation and the update of the topology table.

1. If the sender interface (NB: not originator) of this message is not in the symmetric 1-hop neighborhood of this node, the message MUST be discarded.
2. If there exists some tuple in the topology set where $T_last_addr = \text{originator address AND } T_seq > ANSN$ then further processing of this TC message MUST NOT be performed and the message MUST be silently discarded (case: message received out of order).
3. All tuples in the topology set where $T_last_addr = \text{originator address AND } T_seq < ANSN$ MUST be removed from the topology set.
4. For each of the advertised neighbor main address received in the TC message


```
{
  If there exists some tuple in the topology set where
    T_dest_addr = advertised neighbor main address,
    AND
    T_last_addr = originator address
  then
  {
    the holding time of that tuple MUST be set to
    T_time = current time + validity time
    SND_Topologie = SND;
  }
  Otherwise
  {
    a new tuple MUST be recorded in the topology set
    where
    T_dest_addr = advertised neighbor main address
    T_last_addr = originator address
    T_seq = ANSN
    T_time = current time + validity time
    SND_Topologie = SND
  }
}
```

4.2.3. Calculation of the routing tables

The routing table is calculated on the basis of the information of the neighbor table (one hop and two hops neighbors) and the topology table. In the OLSR protocol, the shortest-path algorithm in the number of hops (Dijkstras algorithm) is used to find paths more than two hops. To introduce the link stability in the selection of paths instead of the number of hops, we used a modified version of the Dijkstras algorithm to find more stable paths among all pairs of nodes (MPR nodes) of the topology table. Our algorithm chooses the path, between two nodes, in which its minimum value of SND is the largest compared to all candidate paths.

5. Analysis of the simulation results

To show the effectiveness of the protocol ST_OLSR, we proceed to compare it with the OLSR implementation in Rogge et al. (2010), which uses the ETX metric and called OLSR_ETX. We implemented

Table 2
Simulation parameters.

Parameter	Value
Simulation area	1000 m × 1000 m
Mobility model	RWP model
Pause time	5 s
Hello interval	2.0 s
TC interval	5 s
Topology hold time	15.0 s (3 × TC_INTERVAL)
Physical layer	IEEE 802.11
Transmit power	0.001 w
Simulation time	1500 s (25 min.)

both the ST_OLSR and the OLSR_ETX algorithms using the OPNET simulation tool.

5.1. Network model

We performed two experiments in which we studied the performances of ST_OLSR and OLSR_ETX. In the first experiment, we varied the number of nodes in the network between 20 and 100 for a fixed interval of nodes' speed (between 0 and 25 m/s). Otherwise, in the second experiment, we varied the nodes' speed (20–100) for a fixed number of nodes in the network (70 nodes).

In both the experiments, the simulation is done on a network area of 1000 m × 1000 m. The mobility model considered is the RWP (Random Way Point) and the Topology Hold Time (the expiry time for entries in the topology table) is fixed to 15 s. Table 2 summarizes the different network parameters used in the simulation.

5.2. Analysis of the simulation results

In this section, we present the obtained simulation results of our protocol ST_OLSR and we compare them to those obtained for the OLSR_ETX protocol. For the simulation metrics, we consider:

- MPR_calcs*: This metric shows the number of MPR calculation.
- MPR_count*: This metric shows the number of MPR in the network.
- Route_Table_Calc*: This metric shows the number of recalculation of the routing tables for each node in the network.
- Delay*: This metric shows the end-to-end delay for successful transmitted packets.
- Packets dropped*: This is a most important QoS metric that shows the impact of the stability on the total number of lost packets in the network.

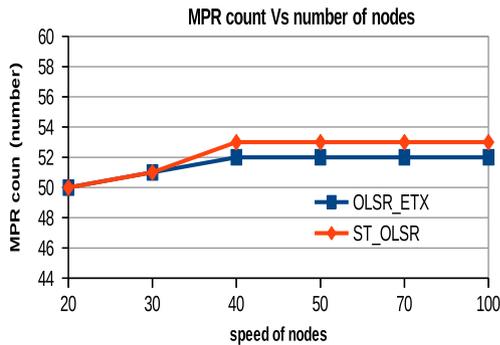
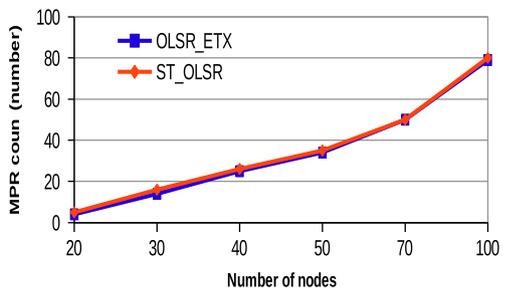
5.2.1. MPR_Count

Figure 6 shows the performance of the MPR count metric for the two protocols. The first and the second experiments are respectively shown in Fig. 6a and b.

Figure 6a shows that the number of MPR nodes grows when the number of nodes increases for the two protocols. We show that by varying the number of nodes, the MPR count is almost the same in both the protocols.

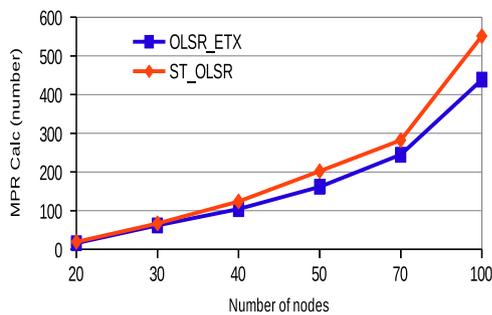
By varying the nodes' speed in the second experiment, Fig. 6b shows that the number of MPR lightly grows relatively with the nodes' speed when it is less than 40. However, when the speed is over 40 m/s, the nodes' speed does not affect the MPR count in the two protocols and the number of MPR in the case of ST_OLSR is lightly greater than OLSR_ETX.

The protocols ST_OLSR and OLSR_ETX elect stable MPR instead of the MPR based on the degree of reachability as is the case in the standard OLSR. Then, the MPR count, when varying the nodes' speed and the number of nodes, is the same for the two protocols.

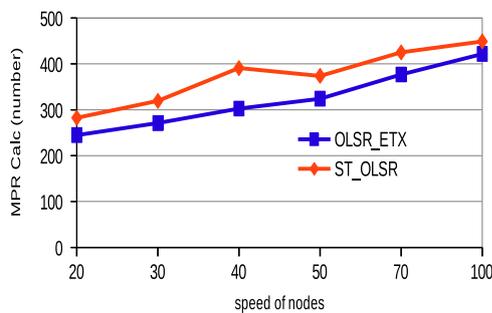


b- MPR count Vs speed of nodes

Fig. 6. MPR_count.



a- MPR Calc Vs Number of nodes



MPR Calc Vs speed of nodes

Fig. 7. MPR_calc.

This means that the protocols have almost the same number of MPR but not the same stable nodes selected by each protocol.

5.2.2. MPR_calcs

Figure 7 shows the performance for the MPR calculation metric of the protocols ST_OLSR and OLSR_ETX. Figure 7a shows the performance for the first experiment while the performance for the second experiment is shown in Fig. 7b.

Figure 7a shows that the number of MPR recalculation in both the protocols increases relatively with the number of nodes. In fact, when the number of nodes increases, the number of MPR nodes relatively grows in the network. We show that the number of MPR recalculation is almost the same in both the protocols if the number of nodes is less than 40. This is due to the minimal number of nodes in the network which requires a minimum number of MPR nodes. However, between 40 and 100 nodes, the ST_OLSR protocol presents more MPR recalculation compared to OLSR_ETX due to its stability metric for electing the MPR nodes.

Figure 7b shows that the number of MPR recalculation in both the protocols increases relatively with the nodes' speed. In fact, more the nodes' speed increases more the network topology changes which implies an increase in the number of MPR recalculation.

We can mention that the number of MPR recalculation in ST_OLSR is greater than OLSR_ETX in both the experiments. Although, the two protocols consider the stability of nodes, the stability metric of ST_OLSR is so sensitive to the signal power variation of nodes which means that ST_OLSR recalculates the MPR, for a time interval, when the signal power variation changes. However, the stability metric of the OLSR_ETX protocol considers the lost packets in the same interval of time. This means that OLSR_ETX has a less frequency recalculation of the MPR.

5.2.3. Route_Table_Calc

Figure 8 shows the performance for the Route Table Calculation parameter of the ST_OLSR and OLSR_ETX protocols in the first and the second experiments (respectively Fig. 8a and b).

As shown in Fig. 8a, the number of routing table recalculation in both the protocols increases relatively with the increase of the number of nodes in the network. This is justified by the increase of the number of MPR recalculation when the number of nodes grows. We show that the number of routing table recalculation is almost the same in both the protocols if the number of nodes is less than 40. From 40 to 100 nodes, the routing table recalculation in the case of the ST_OLSR protocol is greater than in the case of OLSR_ETX, mostly when the number of nodes is equal to 100.

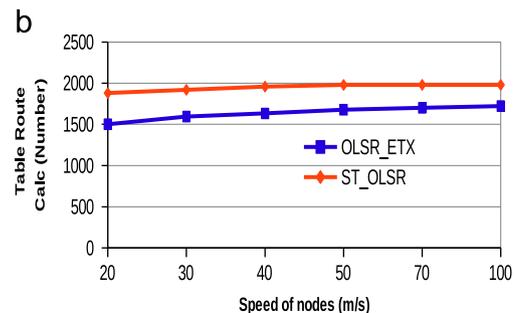
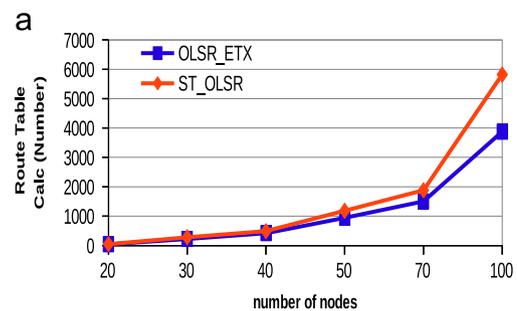


Fig. 8. Route_Table_Calc. (a) Route Table Calc Vs number of nodes and (b) Route Table Calc Vs speed of nodes.

Figure 8b shows that for a given number of nodes (in our case 70 nodes), the nodes' speed does not significantly affect the number of routing table recalculation in both the protocols.

We can note that the number of the Route Table Calculation in ST_OLSR is greater than in OLSR_ETX in both the experiments. In fact, with respect to the number of MPR recalculation, the ST_OLSR protocol has a high frequency recalculation of the routing table than the OLSR_ETX protocol.

5.2.4. Packet dropped

Figure 9 shows the Packet Dropped performance of the ST_OLSR and OLSR_ETX protocols. Figure 9a shows the performance by varying the number of nodes while Fig. 9b shows the performance by varying the nodes' speed.

Figure 9a shows that the ST_OLSR protocol minimizes the number of lost packets when the number of nodes grows in the network. Then, more the number of nodes increases, more the probability to find more stable paths increases which consequently reduces the number of lost packets. This improvement is not fully guaranteed in the case of OLSR_ETX. We show that the number of lost packets in OLSR_ETX is minimized except the case when the number of nodes is between 40 and 70 where the number of lost packets is unchanged. This implies that the path selection metric in OLSR_ETX does not elect the most stable paths as is the case in the ST_OLSR protocol.

Figure 9b shows that the nodes' speed does not significantly affect the number of lost packets compared to the case of varying the number of nodes (Fig. 9a).

By varying the node's speed and the number of nodes, the ST_OLSR presents a less packet dropped than the OLSR_ETX protocol. This is due to the choice of the more stable paths in ST_OLSR compared to the OLSR_ETX protocol. This result agrees with the previous analysis, when the ST_OLSR increases the number of MPR recalculation and the number of the routing table calculation, by selecting in all cases the more stable node.

5.2.5. Delay

Figure 10 shows the performance of the end-to-end delay for the two protocols. The first and the second experiments are respectively shown in Fig. 10a and b.

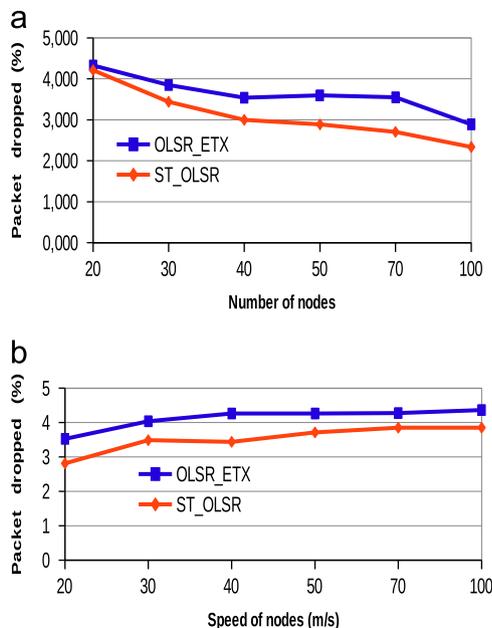


Fig. 9. Packet dropped. (a) Packets dropped Vs number of nodes and (b) Packets dropped Vs speed of nodes.

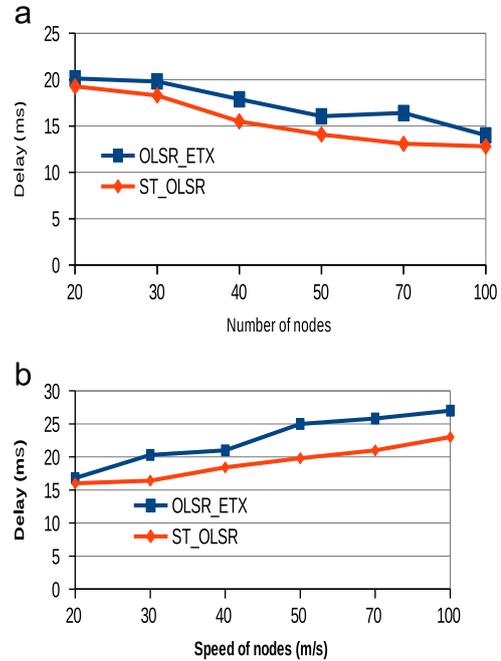


Fig. 10. Delay. (a) Delay Vs Number of nodes and (b) Delay Vs speed of nodes.

Figure 10a shows that the end-to-end delay is reduced when the number of nodes increases in the case of ST_OLSR. In fact, when the number of nodes increases, the number of stable paths increases and consequently the end-to-end delay is reduced. This is not always the case for OLSR_ETX. In Fig. 10a, when the number of nodes in the network is between 20 and 30 or between 50 and 70, the end-to-end delay is unchanged; however is lightly reduced in the other cases.

Figure 10b shows that the end-to-end delay increases relatively to the nodes' speed for the two protocols. However, the end-to-end delay in the ST_OLSR protocol is better than the OLSR_ETX protocol.

We can state that the end-to-end delay in ST_OLSR is lower compared to the OLSR_ETX protocol in all experiments. This is due to the selection of stable paths in the case of ST_OLSR protocol which consequently results in a less path disconnection.

6. Conclusion

In a dynamic environment, such as Ad hoc networks, it is very difficult to provide an ideal solution to satisfy the QoS requirements for different applications. In this paper, we have proposed a mechanism that allows maintaining a stable and sustainable network topology. For this purpose, we have proposed two concepts: SND and FND to elect stable MPR nodes and stable topology. The simulation results have confirmed the effectiveness of our proposed mechanism in terms of delay and lost packets.

The estimation of the link stability is not the unique parameter to evaluate the durability and the availability of the path. For this, and as future works, we plan to improve our work to support other parameters like: the overload of the path, the remaining energy of the nodes constituting the path, etc. On the other hand, we plan to adapt our mechanism to integrate it in other routing protocols, such as: AODV or DSR, and implement it in the real experiment.

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