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Network awareness and dynamic routing: The ad hoc network case

Beatrice Paillassa [a,*], Cholatip Yawut [b], Riadh Dhaou [a]

[a] *Universite de Toulouse, IRIT laboratory, ENSEEIHT, Toulouse, France*
[b] *King Mongkut University North BangkoK, Thailand*

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ABSTRACT

For extremely dynamic networks, such as ad-hoc, the topology change awareness has a crucial impact on the routing performance and consequently many routing protocols adapt their processes to the state of the network, from some network awareness. While several works have already been done on routing adaptations, this paper is more focused on the network awareness topic and the choice of the best metrics for a given adaptation. More precisely, the paper considers the way to represent by means of metrics the node mobility, the link degradation or the graph topology. The notion of metrics is illustrated through two adaptations of two well known ad hoc routing protocols (DSR, OLSR). We evaluate the effect of different metric choices by considering several adaptation strategies to the topology change which are based on the awareness of both the node movement and the number of nodes. We analyze the adaptation strategies and evaluate the performance of the adaptation depending on the chosen metrics. It is shown that the performance of adaptation is strongly correlated to the metrics that are themselves correlated to the network size. A metric combination based on link duration and number of nodes is found to be a good way to represent the topology change.

1. Introduction to dynamic routing

Compared to basic wired networks, the ad-hoc network, which is composed of wireless mobiles forming a temporary network without any fixed infrastructure and any centralized administration, is a very dynamic network [1]. Beyond the routing protocol standards in MANET (Mobile ad hoc Networks) [2–5], many routing protocols are proposed to support in a more adapted way the network dynamicity. They fit some network characteristics like the limited battery capacity, the restricted and variable bandwidth, the variable traffic load and the dynamic topology. The research objective of these dynamic routing protocols is to adapt the protocol behavior based on the network awareness. Table 1 presents several adaptations with their objective and the network awareness required. There are power, link quality, traffic, and topology adaptations.

Power adaptation. The routing protocol chooses the best route according to a routing metric based on the available power (MBCR [6], MMBCR [7] and MRPC [8]), with different ways to compute this metric. Computation is either local to each node [6] or is global and the metric reflects the available power of several network nodes [7]. Besides, the parameters of the metric computation vary for each protocol. For example, the metric computation includes a residual power parameter in [8] as it selects the nodes belonging to a route according to the available power at the given time and also, to the estimated power that will be consumed by the transmission on the selected link. In fact, this last power parameter depends mainly on the link quality. In order to minimize some inefficient processes of the adaptation, other routing protocols adapt their route computation to the variation rather than to the absolute value of the link quality and adaptation is triggered upon some threshold value.

Link quality adaptation. The link quality is basically obtained from the awareness of the signal strength and of the lost rate. The signal strength reveals the channel state

* Corresponding author.
E-mail addresses: Beatrice.Paillassa@enseeiht.fr (B. Paillassa), cyawut@enseeiht.fr (C. Yawut), Riadh.Dhaou@enseeiht.fr (R. Dhaou).

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Table 1
Adaptive protocols in MANET.

Adaptation objective	Network awareness	Protocol examples
Available power	Power	MBCR: Minimum battery cost routing [6] MMBCR: Min–max battery cost routing [7] MRPC: Maximizing network lifetime for reliable Routing in wireless environment [8]
Link quality	Signal strength	SSA: Signal stability-based adaptive routing [10] ABR: Associativity based routing [11] ASBM: Advanced signal strength based link stability estimation model [12] Link quality of route [13]
Link quality	Lost rate	LD-ARF Loss differentiating auto-rate fallback [14] RBAR Received – based auto rate [15]
Traffic load	Quality of services parameters	DLAR: Dynamic load-aware routing [16] LBAR: Load balanced adhoc routing [17] FDAR: Free-degree adaptive routing [18]
Topology change	density, mobility	AZRP: Adaptive zone routing protocol [20] CSR: Cluster source routing [21] F-OLSR: Fast optimizd link state routing [24] ARPM: Adaptive routing protocol for Manet [22]

and more precisely its stability, it can be computed either from an analytical modeling based on a predictable node movement as in [9], or from real measures (SSA [10], ABR [11], ASBM[12]). Many works establish the link quality by measuring the frame flows at the MAC level (medium access control). In [13], a metric is proposed to measure the link quality in the 802.11 network from the number of data units and acknowledge units that are exchanged. The link quality and the signal strength are also considered as parameters, for several transmission rate adaptations in IEEE 802.11 networks, with the objective to define the transmission rate in function of the channel quality. In [14], the link quality is computed from the rate of the lost MAC frames, aiming not to confuse a busy channel generating collisions and a noisy channel, as the transmission rate has to be decreased only for noisy channels. In another way, [15] adapts the transmission rate from the signal to noise interference which is measured on some MAC frames (the request to send frames).

Traffic adaptation. The traffic load participates as well to the network dynamic. It mainly influences the quality of service experimented in the network, since in case of high load, the delay and the error rate increase. Many studies on routing protocols propose to select a low loaded route and/or to balance the load among various routes to reduce the network delay and the congestion.

Dynamic load-aware routing (DLAR) [16] is a source routing protocol which selects, with a load balancing objective, the nodes of a route in function of their load. The load of a node is expressed as the number of packets in the link buffer. Load balanced adhoc routing (LBAR) [17], in order to assure the smallest delay, computes the load metric from the route number that passes through a node as well as through its neighbors. Thus, the load interference effect for the access to the contention channel at the MAC layer is integrated. Free degree adaptive routing (FDAR) [18] improves the metric computation by taking into account the packet length. It also includes the effect of the access contention to the channel, but this time it is not measured at the routing level but, at the MAC level, from the frame error rate. The metric computation is based on data from the layer 3 routing, the packet number, and from the layer 2 MAC, the frame number. It is a cross layer metric computation.

Topology adaptation While MANET protocols are naturally able to manage the topology dynamic, the adaptive protocols focus on the topology change occurrence frequency: frequent or not. Depending on the network awareness, the routing protocol can choose its route as well as its structure. The structure of the routing protocol is flat when all the nodes have the same routing functions or it is structured when some dedicated elements achieve specific functions. Zone routing protocol [19] is a structured routing protocol that organizes the network in disjoint routing zones. There is a proactive internal zone routing that learns the totality of the routes inside the zone, and a reactive external one that establishes the route on the demand.

As stated in [19], the performance of the routing protocol is strongly dependent on the chosen structure. Adaptive zone routing protocol (AZRP) [20] proposes to dynamically adapt the network structure, by defining the zone radius in function of the network mobility while Cluster Source Routing (CSR) [21] only structures the network when some specific conditions of mobility are observed.

Density metrics and mobility metrics are commonly used for topology adaptation. Adaptive Routing Protocol for MANET(ARPM) [22] starts by using the proactive behavior and then it dynamically eliminates routing tables and switch to reactive behavior whenever the mobility degree, expressed as he neighboring change rate, exceeds a certain threshold. Adapting to Route Demand and Mobility (ARM) [23], and Fast-Optimized Link State Routing Protocol (Fast-OLSR) [24] define also the rate of neighbor change as mobility metric, to adapt the OLSR routing updates so that routing performance is improved, thanks to a more accurate topology and a reduced overhead. ARM computes an aggregate metric by averaging the mobility metric, obtained by dividing the number of neighbor changes (sum of the numbers of new neighbors and old neighbors) of the given node by the mobility metrics of its neighbors. In Fast-OLSR, the proactive routing OLSR measures the mobility from the signal strength and a node reduces its Hello timer value (equivalent to the OSPF – Open Short Path First-one), when this metric reaches a predefined threshold.

In a different way, some protocols use the density metric as the number of network node per unit network area (unit is defined by the transmission range and the area dimension). The objective is to improve the scalability by adapting the flooding part of the routing algorithm. Density Adaptive Routing protocol (DAR) [25] is a position based routing that uses the local network density to determine the packet forwarding zone; in dense areas, it narrows the forwarding range to reduce the total number of participants in flooding; in sparse areas, it enlarges the forwarding scope to enclose enough nodes for packet relaying. Location Aided Knowledge Extraction Routing (LAKER) [26], uses population density distributions for route guiding and to pass around the void area.

Beyond the dynamic routing review, the original question of the paper is "how to capture the topology mobility and how to use it?". There are few works on topology change awareness, mainly concerned by mobility model research. Elsewhere, metrics are proposed for protocol adaptation but they are not evaluated in terms of efficiency for an adaptation. The adaptation proposed by the researchers is evaluated with only one chosen metric. In the paper, we put forward the importance of the chosen metric (called adaptation strategy) in terms of protocol performance. Different metric choices are evaluated by considering several adaptation strategies to the topology change, which are based on the awareness of both the node movement and the number of nodes. The rest part of the paper is organized as follows. Section 2 specifies the protocol adaptation process; it considers the protocol and the metrics that reflect the topology dynamic. Section 3 illustrates the adaptation process through two adaptations of MANET routing protocols. Section 4 analyzes the adaptation strategies and evaluates the performance of the adaptation according to several choices of metrics.

2. Adaptation process

The protocol adaptation process is based on three sets of elements: the protocol to adapt, (i.e. the algorithms to apply depending on the network state); the network awareness (which is perceptible through *metrics);* and finally the performance to optimize with the adaptation (such as efficiency, delay, overhead, power or the packet delivery ratio (PDR)).The protocol and the network awareness elements are detailed as follows.

2.1. Protocol adaptations

The different ways to achieve the protocol adaptation, mainly concern the chosen method, the policy and the signaling. The method involves one or more protocol layers, the policy concerns the adaptation object, either the parameters or the mode, and the signaling supports the network awareness. More precisely:

Self and cross layer method. If the parameters of the metric are originated from a single layer (the one the protocol to adapt belongs to) then, the adaptation method is called self-adaptation. When the parameters are generated from several layers we deal with cross-layer adaptation. Indeed, self-adaptation is a classical function of the OSI or TCP/IP architecture, each layer is independent from the other: modifying a layer does not affect another one. Cross layer adaptation breaks the axiom of ISO layer involving an exchange of information between layers which may be either adjacent or non-adjacent. The protocol stack and architecture are currently not standardized, although some standards the IEEE in particular set up a control plan or a management plan that facilitates the cross-layer protocol design.

The advantage of the cross-layer adaptation is an improved performance. However, this system is more difficult to implement in the existing architectures, and more difficult to maintain than a system with self-adaptation. Furthermore, in the case of cross layer adaptation, a consistency problem occurs when a level changes the parameters which are taken into account for a metric calculation by a higher level, because the veracity of the metric is impacted. For example, consider a network that performs rate and routing adaptations based on signal strength. As the rate adaptation changes the signal metric value, the measured signal parameter can not really reflect the network dynamic. Measuring scale has to be finely analyzed.

It is simpler for routing adaptations to avoid some potential problems and then to measure parameters from level 2 or from the routing level 3 that will not be adapted, rather than measuring parameters from physical level that may be adaptable. Meanwhile, one way to solve this problem, proposed in the architecture Widden [27], is to trigger an adaptation of the N level only if an adaptation of the $N-1$ level has be proved ineffective. Therefore, it is useful to define a handoff state (limited by timer) for a N level optimization before triggering an optimization of the $N+1$ level. It has to be noted that, in traditional architectures, this problem does not appear because each protocol self-adapts its behavior from internal parameters, then, the performance is possibly not optimized but it is not degraded.

Parameters and mode adaptation policy. Parameter adaptation is the basic policy of a protocol that sets its parameters according to the state of the environment. Examples of such adaptations are the transport protocols that compute the congestion window according to the transmission rate parameter. There are also routing protocols which choose the route depending on the stability, the delay, or which adjust their update routing timers (for proactive routing) based on the network mobility: if the network sustains high mobility, the broadcast timer is short duration while it is long in low mobility case. For the mode adaptation policy, rather than parameters, the protocol changes its behavior depending on its environmental conditions. For example: a transport protocol stops to increase its retransmission timer if an important level of mobility is detected [28]; a routing protocol works in a certain mode (e.g. flat routing) and when the number of nodes increases, it switches to another mode (e.g. structured routing) [21]. To achieve a mode adaptation in a network, it is necessary either to synchronize the system in order to get each node in the same mode, or to define some compatibility rules in such a way that network elements in different modes can operate together. Because of the lack of centralized control, the system synchronization is not recommended in ad hoc network.

In-band and out-band signaling. When a node gets the network awareness from the protocol to adapt, it is called an in-band signaling, while when it comes from an additional protocol, it is an out-band signaling. A common in band signaling is the Hello protocol that is included in many protocols, as in the OSPF protocol or in the OLSR and AODV routing protocols. The Hello signaling obtains the network knowledge by periodic broadcasts of Hello messages from each node to its neighboring. Objective is to get the neighbor identity with some additional information, or to deduce from the received message, some information. Hello protocol is generally associated to the proactive routing (i.e routes are computed even if there are no data to exchange) meanwhile, for the reactive routing (which looks for a route on the demand), there is also some in-band signaling, as it integrates a route error management process. The generated error messages are useful to set mobility metric values. One can note that, ICMP and ARP protocols are also able to get the network awareness.

2.2. Topology change awareness

The choice of a metric valuating the change of topology differs, if the objective is either to evaluate some protocols over mobile network environments, or to adapt a protocol. In function of the given objective, the selection is more influenced by a cost criterion or a veracity one.

Metric objective : adaptation or evaluation. The metric is the instantiation of the network awareness concept; it gives values that are used to adapt the protocol behavior. Concerning the topology change metric, it has to reflect the network connectivity graph which changes, when a wireless link is degraded in the way that that the connectivity graph is disrupted and, or, when a mobile node moves oppositely to its neighbors, in such a way that links appear or disappear. The death of a node due to an insufficient power can be viewed as a major link degradation, and the addition or the deletion of a node can also be considered as a special case of mobility. When investigating the researches on mobility [29], many ways to represent it are perceived. A first set of studies aims to set up some mobility models in order to compare different routing strategies [30,31] according to several evaluation metrics. A second set of studies evaluates metrics to propose adaptations [32]. Thus, the metric appreciation depends on its object: adaptation or evaluation. For the former purpose, the metric cost in term of processing or signaling, is of a primer importance while for the latter, the metric veracity is the main point.

Metric cost. From a general point of view, although the measurement process by active listening is a costly process in terms of consumed power, the computation process is considered as more expensive when a mathematical model is applied than when it is based on measurement (measured power value, number of errors, number of messages received from neighbors, etc). For the signaling aspect, it depends on the metric scope: local scope, route scope or global scope. The local metric concerns the neighboring; it generates less signaling than the route metric which is related to the path between two stations, which in turn generates less signaling than the global metric about the total network. The global metric is usually used as an evaluation metric. For instance, in [33] mobility metric characterizes a scenario by averaging over all node pairs their absolute relative speed taken as an average over the time. The route metric and the local metric are classically used as adaptation metrics. For example, [34,35] model the route stability metric to improve the performance by choosing the most stable route. Authors of papers [10,11] tend also to choose a stable route, but this time, the stability is computed from a metric that is local (obtained from the signal strength measurement).

Veracity degree. It is correlated to the network performance gain generated by the adaptation. As the aim is to efficiently manage the network dynamic, a right metric which would influence the performance has to reflect the network connectivity graph. In case of graph disconnections, the performance is reduced while it does not on the contrary. Hence, researches on routing adaptations consider two main parameters that affect the graph: the *mobility* parameter reflecting the node movement, and the *density* parameter describing the number of nodes. The number of nodes, or degree, is measured in the OLSR protocol and modeled in the Kinetic Multi Point Relay adaptation [36] to choose the element of the network structure. The nodes which have the highest degree are chosen. The degree may be obtained, with limited overhead, by using either a neighbour detection protocol or by exploiting some cache information (such as the routing cache or the Address Resolution Protocol cache). Concerning the node movement, the literature presents two approaches: firstly, the metric is computed from the past history of the movement (by means of measures), secondly, it is computed from prediction and modeling of the future movement. Basically, the movement is supposed to be linear or linear by step [35] and, from the speed knowledge or the positioning knowledge, it is possible to predict the movement of a station [37].

Basic mobility metrics. As stated in [38], a metric presenting good characteristic has to be: computable in a distributed way without global network knowledge, able to indicate or predict the protocol performance, feasible to compute (in term of resource consumption), independent of any specific protocol and computable in real network. Thus, local metrics computed from measurement are preferable. Meanwhile, as positioning could not be deployed on basic equipment, it is preferable to get indirect measure of the mobility through network monitoring. The good metric has to be function of the routing protocol to adapt and of its in-band signaling capacity. Precisely, there are protocols with in band neighboring discovery signaling for which the basic measured metrics are the degree, the frequency of Link State Changes (*LC*), the Link Connectivity Duration (*LD*) and the Link Stability ($LS = LD/LC$). Simulation results in [29] highlight the salient of the average *LD* which would be the best metric among all the three mobility metrics since it is well correlated to the network performances. It offers the best veracity model (for random mobility models: Random Way Point, and Reference Point Group Model). *LD* is introduced by LS-OLSR [39] to select a stable structure in the OLSR network.

3. Illustrations of protocol adaptations to dynamic topology change

In this section, the adaptation process of the dynamic routing is illustrated through two examples, one concerns the DSR (Dynamic Source Routing) protocol and the other one is related to the OLSR protocol. The objective is to adapt these two protocols to the network topology changes, according to density and mobility metrics.

3.1. DSR adaptation

DSR [5] is a source routing protocol standardized for MANET. Routes are retrieved, on demand, by broadcasting a route request on the network. Route reply, is sent back by the destination and then the route contained in the reply is cached at the source. We developed Cluster Source Routing (CSR) [21], as a mode and parameter adaptation of DSR. It increases the scalability of the standard protocol with regards to the network size and the network mobility. The DSR routing mode is source routing on flat network while the CSR routing mode is source routing on clustered architecture. The clustered architecture is a structured network organization composed of a set of connected cells with a designated node in each cell (the cluster head), it decreases the routing overhead in large networks. But, even for large network, it can also induce an important routing overhead if the network clustering has to frequently change. Thus, the adaptation objective is for a station to, automatically, in function of the network awareness, switch from the flat mode to the structured mode.

The adaptation procedures are totally transparent and ensure full compatibility between nodes using native standard and nodes using the adaptation. In practice, the adaptation is conceived as an extension that conserves the packet format, and thus, native and extended nodes can communicate with the standard protocol. The procedures are carried out through the standard option codes that are chosen to allow native standard nodes to treat packets if necessary.

3.1.1. Routing procedure in clustering mode

The adaptation routes the data through a structured network that is supervised by a server. Precisely, the network is viewed as a set of cells, each one containing a cluster head node that is one hop away from all the nodes of the cell, and a given cluster head is selected as server (see 3.1.3). Instead of diffusing a route request in the entire network, as DSR does, with the adaptation the route request is directly transmitted to the server (transparently to the source node because the cluster head manages this request) which acts as a global route cache. Either the server knows the answer (the node is located to a cell and the route between the cells is known), and it replies to the requested station, or it undertakes to send a route request in each cell. Upon the reception of this request, the cell leaders locally broadcast it and then, the requested node will unicast the route reply to server that finally, will retransmit it to the requesting node (in the standard, the route reply is directly unicasted from the requested destination to the source). The routing information is then cached at the source station, as in the standard, and also at the server (so, the station localization is registered). In case of successive failures of route, the request is broadcasted through the all network. Thus, routing adaptation is completely transparent to the nodes: a standard node without this extension can operate in the network.

3.1.2. Adaptive clustering procedures

The set up of cells is done by the highest-connectivity degree algorithm from the *degree metric*. The node with the highest number of neighbors, or degree, is chosen as Cluster Head (in case of equality, the lowest IP address is preferred). The election process can also be adapted to the node movement by choosing the more stable element. In order to achieve the adaptation process in a decentralized way (i.e. each node decides by itself to adapt or not), different states have been considered: DSR, CSR and native DSR, with a switching from DSR state to CSR state and vice versa. More precisely, the network element is designed with status:

- *Undefined*, the element has not yet obtained a valid status and is running the native DSR protocol;
- *Node:* the station can run the CSR mode;
- *Cluster Head:* the element is the cluster leader of the cell.
- *Server:* it is the leader of all the cluster heads.

When a node enters the CSR routing mode, it initiates the Get-Status procedure by locally broadcasting a route request which contains its election criterion and indicates its undefined status. If a packet from a Cluster Head is received, the node initializes its status to node. Else, on receiving a request packet, the node actions depend on its state mode. For *CSR mode:* the node compares the election criterion of the received packet with its own. If its own is better, it becomes Cluster Head, sends a packet, and then its neighbors will become nodes. For *DSR mode:* the node checks its adaptation parameter (see 3.1.4) and if it is suitable enough to switch to the CSR mode, the node starts the Get-Status procedure. Finally for *native DSR:* it just discards the packet (unknown option code).

3.1.3. Adaptive server selection

Server is elected among the Cluster Heads that initiate an election by broadcasting an Election packet (DSR route request with an option containing the election criterion), only treated by the peers. If the received election criterion is better than the node one, the election packet is re-broadcasted by the Cluster Head that appends its own address in the record listing. Moreover, the node records the server candidate address and the route to reach it. Thus, the CSR routing will be transparent since, upon a route request, the Cluster Head can transparently to the station, direct the request to the server. It just adds the needed routing information. At the end of the election (detected on timer expiration), the best candidate declares itself as the server and each Cluster Head registers to the new server. Thus, it knows all the Cluster Heads and their routes. If the network is connected, there is only one server, else a server is elected in each partition of the network.

3.1.4. Network awareness: density and path failure parameters

The network awareness is useful to set up the election criterion of the election processes and to set up the criterion for the DSR_(CSR) mode switching. As stated previously, the network mobility awareness is represented by two

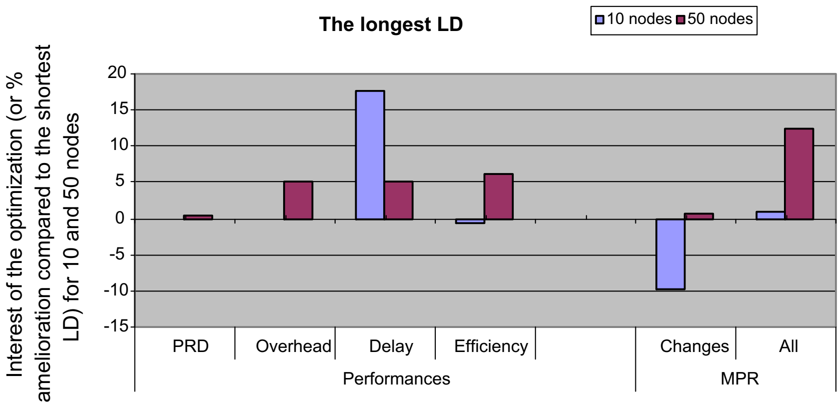


Fig. 1. Protocol performances gain with longest *LD* for 10 and 50 nodes.

parameters: the mobility that reflects the node movement and the local density parameter. In order to reduce the metric cost, the mobility metric is chosen as the number of Route Error (DSR-in band signaling), and the number of neighbors registered in the route cache provides the density metric. The metrics are periodically computed. The developed protocol, switches to DSR mode if it experiences more CSR errors than a predefined MAX value (set to 3 by default). Moreover, the mode switching occurs in case of failure in setting up the architecture. Thus, on receiving an ABORT packet from the server, a node switches to DSR mode. Server sends an ABORT packet when it is about to give up its role, (i.e. the number of registered cluster heads is too small).

3.2. OLSR adaptation

The other developed adaptation concerns OLSR [3]. Quite similar to the internet routing OSPF, OLSR computes routing tables from topology information broadcast. However, it differs in its topology organization: OLSR computes a virtual topology composed of Multipoint Relays (MPR) and routes the data through the MPRs. The purpose of the MPR is to reduce the information exchange overhead as only the MPR broadcast the topology information.

3.2.1. Adaptive MPR selection

The main criterion of the standard MPR selection algorithm is the reachability number of two-hop neighbor nodes, a *density metric*, it is computed from periodically broadcasts of HELLO messages. The given node chooses the nodes that will broadcast its topology announces, its MPR, the one-hop neighbor nodes that reach the maximum number of two-hops nodes. We developed an adaptation which introduces the link Duration parameter (*LD*) in the MPR selection algorithm. The objective is to choose a "stable" MPR that has low probability to move and would remain MPR.

3.2.2. Network awareness: density and link duration parameters

Over the density parameter of the standard OLSR version, a mobility parameter is computed from the Link Duration metric. As for the degree computation, a station computes its *LD* values with the HELLO signaling. When it receives a HELLO message from an unknown neighbor, the station creates a link tuple that can be easily completed by a "Start Connection Time" (Start_t) parameter.

Concerning the *LD* value, MPR selection can be either on the largest or on the smallest values. The largest selection policy supposes that a node with long connection duration is a stable node, while on the contrary, for smallest selection policy, a node with a long duration is not stable as it is premised that it would move soon. The validity of the assumption is function of the considered mobility model. Considering that the mobility model is unknown, the random way point model [40] can be selected to validate the largest or smallest hypothesis. We proceed to simulation.

Fig. 1 indicates simulation results with NS2 simulator [41][1] on the impact of the largest and the smallest *LD* on the protocol performances. The percentage of performance improvement of the largest *LD* compared with the shortest *LD* is represented for 10 and 50 nodes. A positive value indicates that the largest *LD* policy performs better than the shortest one. The reported values concern the network performances (*PDR, overhead, delay and efficiency*[2]), the number of MPR changes, (*change*), and the total number of MPR, (*all*). It indicates that the longest *LD* policy for 10 nodes performs better than the shortest *LD* policy does over a delay about 17.673 % even if the number of MPR changes and the efficiency are higher (in the figure, the interest of optimization for this performance parameter is negative). In fact, on a small network the control traffic generated is less influent than the length of the route, due to an important number of MPR. For 50 nodes, also the longest *LD* performs better than the shortest *LD* in all the aspects. Note that, another

[1] Results are obtained from 15 scenarios for each pause time, maximum speed Vmax is 10 m/s, pause time vary from 100 s to 500 s by step of 100 s. Traffic is Constant Bit Rate (CBR), 4 packets/s, length 512 bytes. Simulation area is 1000 m $\times$ 1000 m with a 802.11 radio range of 250 m for 10 and 50 nodes. Sources are 3, 10 and 15 sources for 10, nodes. The source-destination pairs are selected randomly. Simulation time is 1000 s.

[2] **Efficiency** (%) is the number of delivered packets which are transmitted (Data)/(Data + Routing Overhead) where Routing ; **Overhead** is normalized routing overhead = 100 $*$ (RP + ROD)/Packet where Routing packet (RP) are counted per hop in bytes and, Routing Overhead on Data packet (ROD)in byte; **Delay** (seconds) caused by buffering, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times

reason to choose the longest LD rather than the lowest one, concerns the observation period. For longest LD, the observation period should be set long enough to capture the data of the longest link survived by the node, so it may be difficult to achieve in practice.

4. Choice of the adaptation strategy

The previous section has presented two protocol adaptations, this one focus on the metric choice. It analyses different strategies that combine mobility and density. The metric veracity is established by simulation and the best strategy leads to the best performance improvement. Performance is expressed through common parameters, as delay and packet delivery ratio, both with specific protocol parameters (number of cluster head, MPR, etc). Results are obtained from protocol implantation over the NS (2.30) simulator. Conditions are similar to those of many works on ad hoc protocol, they are derived from [42], the basic mobility model RWP is used and 15 scenarios have been run for each variation of the mobility model. The radio range of IEEE 802.11 transmission is 250 m for 50 nodes and 150 m for 100 and 150 nodes. Nodes are randomly distributed over a 1000 $*$ 1000 m area. For CSR adaptations, simulation time is 1000 s whatever the node number, for OLSR, in order to reduce the required time and CPU resources, simulation time is 250 s when the node number is 100 and plus (same time is taken in [43]). We synthesize results by averaging scenarios results on figures.

4.1. Mode adaptation strategies

We consider four strategies to switch from a routing mode without infrastructure to an infrastructure one, they are:

- NA-CSR: it is non adaptive; the nodes are and remain in the infrastructure mode.

Other strategies are adaptive (A-CSR) and differ about their metrics:

- A-CSR($M+D$) it is based on both Mobility, and Density metrics,
- A-CSR(M) depends only on Mobility metric,
- A-CSR(D). uses only Density metric.

In case of low values of Density and/or Mobility, a network node is in a given mode and it changes the mode as metrics get high values. The mode change process is defined on Fig. 2 ([21]). The values of the metric thresholds are chosen on experimental simulation results: $M1$ (low) = 2, $M2$ (high) = 4, $D1$ (low) = 2 and $D2$ (high) = 5.

Fig. 3 shows the efficiency, depending on several node numbers, for DSR, NA-CSR and A-CSR with the 3 strategies of switching: Mobility (A-CSR (M)), Density (A-CSR(D)), and Density + Mobility (A-CSR($M+D$)). Each point corresponds to 60 mobility scenarios (15 scenarios for each pause time variation in RWP where pause time varies from 100 to 500 s and vmax = 10 m/s) as stated on the figure, the strategy efficiency depends on the node numbers in a given area:

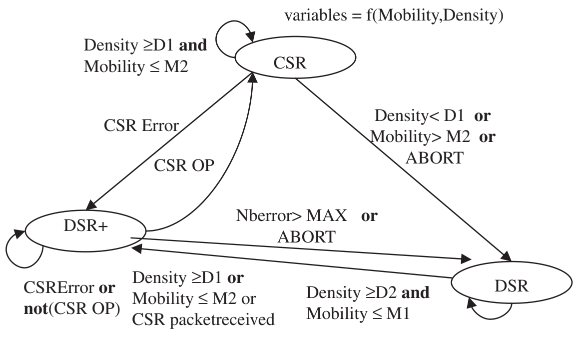


Fig. 2. Principle of mode adaptation in DSR/CSR.

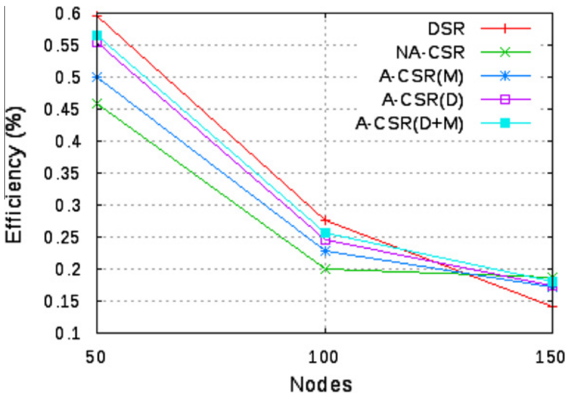


Fig. 3. Strategies of adaptation : the mode switching efficiency.

- **For 50 nodes**, naturally the standard (DSR with no adaptation) is the most efficient, as a flat routing protocol is suitable for a small network, and NA-CSR is the least efficient due to the cost of the cluster set up and maintenance that is too high. Also, the mobility strategy performs lower than the density one and than the joint (Density + Mobility) one: nodes often detect favorable conditions (low mobility) to a mode switching (DSR -> CSR) but the density is too low and then the cost of the structure is disadvantageous in comparison to the cost of dissemination.
- **For 100 nodes,** NA-CSR performs still lower than the standard and all adaptive strategies but much closer than in 50 nodes density: the node density becomes suitable enough to use a hierarchical routing. Note that, the mobility strategy functions lower than the other strategies. The density criterion is still most interesting to be considered. The Density alone strategy performs slightly worst than the Density + Mobility one because the node density is suitable enough and there are several nodes with the same density, so that Mobility metric is then considered as a secondary criterion.
- **For 150 nodes,** of course, the standard performs badly, as the network conditions in terms of density are most favorable to hierarchical routing (NA-CSR) than to flat routing. The (Density + Mobility) strategy performs better than the Density one (A-CSR (D))and better than the Mobility one (A-CSR(M)), but slightly lower than the non adaptive clustering solution (NA-CSR) due to some adaptation cost.

Thus, whatever the network size is, there is an interest to protocol adaptation. The efficiency of the adaptation is always between those of the two non adaptive protocols: pure hierarchical and flat routings. Moreover, we note the interest of the joint strategy (Density + Mobility) which has a behavior close to the most efficient routing method regardless of the network size: for a network varying in size and that is not too mobile, there is interest to dynamically set up a cluster structure. In the following, A-CSR is simply noted CSR.

4.2. Parameter adaptation strategy

The network awareness aims to choose stable elements for the two protocol structures (clustering and backbone) in order to reduce the maintenance cost of the structures. Also, the question is to determine the notion of 'stability' in terms of metrics. It may be preferable to choose a node with a lot of neighbors, because it is supposed that in case of movement it will be able to reconnect rapidly the network graph, or, it may be better to adopt a mobility strategy by selecting a node that does not move, in order to favor the existing graph connection. Furthermore, a combined strategy may be efficient too. Thus, we evaluated density and combined density/mobility strategies. Considering that the density strategy is the standard strategy, the interest of a given strategy is expressed as its percentage of improvement compared to the standard strategy. Strategy notation is given in Table 2.

4.2.1. Clustering parameter

To select stable Cluster Heads and Server, three proposals of metrics are considered:

Table 2
Adaptation strategy-notation.

	CSR protocol	OLSR protocol
Mobility metric	E: route error	LD: link duration
Density metric	D: node degree	D: node degree
Adaptation strategy		
Density	CSR $1D$	OLSR $1D$
Mobility then density	CSR $1E + 2D$	OLSR $1LD + D$
Density then mobility	CSR $1D + 2E$	OLSR $1D + 2LD$

- CSR $1D$ only considers the density through the number of neighbors, it is the standard method.

The two other strategies combine the mobility to the density in different order of applications.

- CSR $1D + 2E$ firstly (1) selects the elements from the density criterion (D) and secondly (2), in case of equality, from the number of route error (E) criterion.
- CSR $1E + 2D$ strategy inverses the order of the criteria.

For the evaluation results, a positive value in the Figs. 3–5 indicates that the metric strategy is good, as it improves the protocol performance.

4.2.1.1. Strategy evaluation in low density. Although CSR gains performance for large network configuration (Fig. 3), the interest of the mobility awareness is evaluated for small configuration: 50 nodes (on simulations, if less than 50 nodes, CSR can not operate because the density condition is not enough to change the mode from DSR to CSR). The percentage of performance improvement, is indicated in Fig. 4.

For the two strategies, the total *(all) number of Cluster Head and Server* is not important (less than 1%) as the density condition leads generally to a flat mode. However, the numbers of *Cluster Head and Server change* of the combined strategies are lower (improvement less than 5%) than of the basic strategy thanks to the mobility criterion. As the density network is low, due to the value of the adaptation threshold, the two combined strategies choose quite the same number of elements. For the other performance parameters, *PDR*, *overhead*, *delay* and *efficiency*, it is shown that mobility is more influent than density. The "Mobility + Density" strategy ($1E + 2D$) offers the best percentage improvement in terms of delay (because the Cluster Head and Server are less changed, routes are also less changed). The other performance improvements are not significant (less than 1%), because all strategies can use the DSR procedures to keep packets until a route to the destination will be available.

Thus, mobility metric is more influent than density metric in small environment.

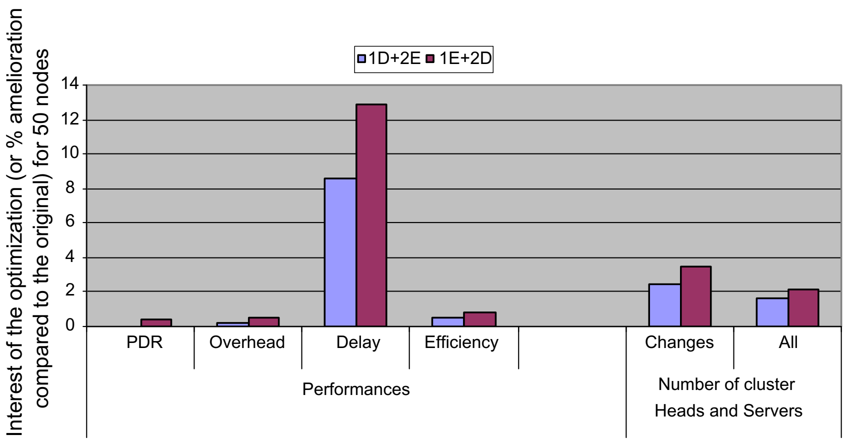


Fig. 4. Comparative performances of DSR adaptation strategies for 50 nodes.

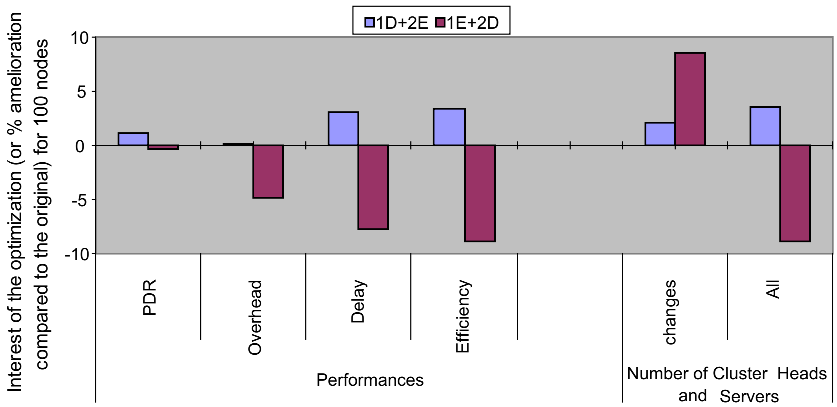


Fig. 5. Comparative performances of DSR adaptation strategies for 100 nodes.

4.2.1.2. Strategy evaluation in medium density. Fig. 5 presents the performances for 100 nodes. It indicates that the combined strategies ("Density + Mobility", "Mobility + Density) do not improve the performance compare to the standard strategy ($1D$).

$1D + 2E$ has nearly the performance of $1D$ (less than 4% of difference). A given node has several one-hop neighbors which perhaps have to cover few or several two-hop neighbors. Therefore, it has low probability that one-hop neighbors have the same density. Hence, the mobility criterion has a low probability to improve the performance, as it would be rarely applied. $1E + 2D$ strategy just increases the improvement percentage of the *number of Cluster Head and Server changes*. The *change* parameter does not relate with other performance criteria: the strategy $1E + 2D$ induces an important number of Cluster Head and Server but they do not change too much. For all other criteria, the performance decreases with the adaptation Hence, the density is more influent than mobility metric when the network size increases. It is preferable to choose a node with a lot of neighbors even if it frequently changes of neighbors. This result is confirmed for larger configuration in the next paragraph.

4.2.1.3. Strategy evaluation in high density. Confirming the previous results on 100 nodes, performances on 150 and 200 nodes are respectively noted in Figs. 6 and 7. The combined strategy, density then mobility, ($1D + 2E$), performs better than the density strategy ($1D$) for all performance criteria.

Delay is lower due to route stability improvement (*number of Cluster Head and Server changes* is lower). For high density network, the performance is inversely proportional to the number of Cluster Head and Server change; the number of route changes decreases as well as the end-to-end delay, because the route availability and the number of control messages which are broadcasted are also reduced. As a result, *PDR* is improved. Furthermore, the combined strategy uses fewer elements (*all*) because of mobility metric assistance. The Cluster Head and Server candidate nodes are higher than with the previous network sizes; a given node has many one-hop neighbors which perhaps have to cover few or several two-hop neighbors. Therefore, it has high probability that several one-hop neighbors have the same density. Hence, the E metric has a high probability to improve the protocol performance.

Fig. 8 summarizes the results obtained concerning the strategy benefits, in terms of delay efficiency, for different network size. For low density environment, the mobility metric strategy improvement is more significant than the density one, the optimum metric choice would be "Mobil-

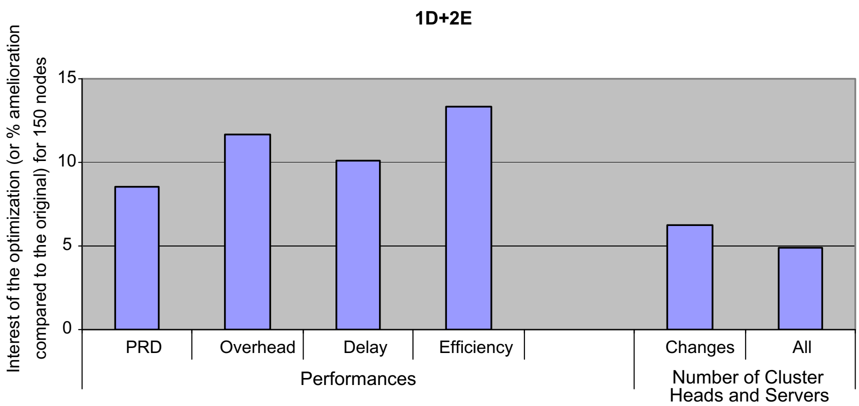


Fig. 6. Comparative performances of DSR adaptation strategies for 150 nodes.

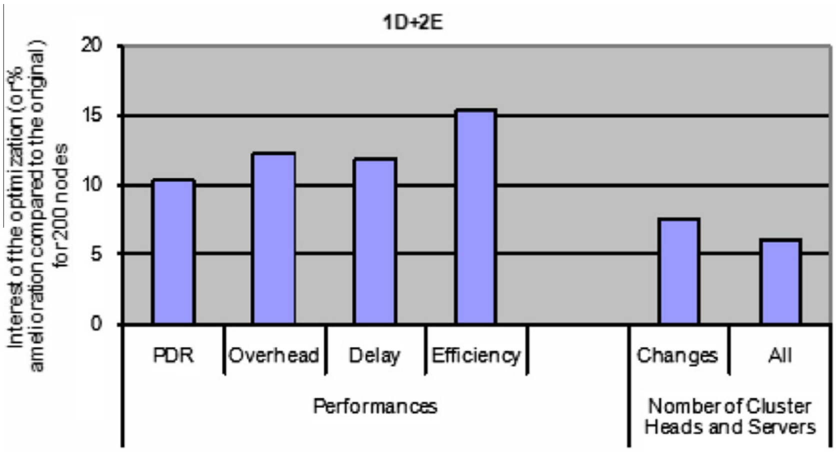


Fig. 7. Comparative performances of DSR adaptation strategies for 200 nodes.

ity". Nevertheless the "Density + Mobility" strategy improves the performance. For medium density, the optimal choice would be Density while for high density it is the combined strategy, density then mobility, which is preferable. Analytical work presented in [25] confirms these results. In sparse networks the mobility has a positive effect on connectivity, whereas in dense network the situation becomes the opposite.

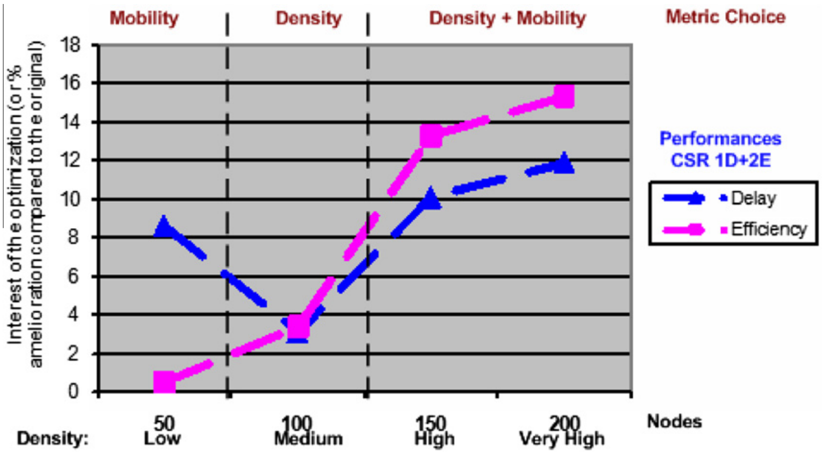


Fig. 8. Interest of the adaptation strategies with the network size for DSR adaptation.

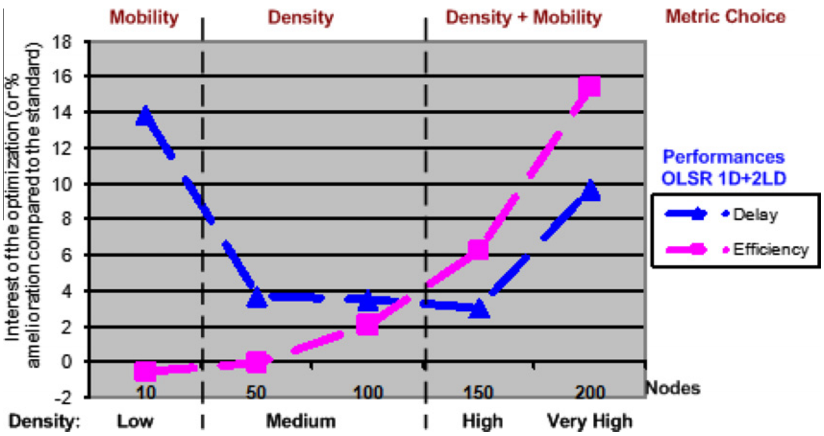


Fig. 9. Interest of the adaptation strategies with the network size for OLSR adaptation.

It appears that the "Density + Mobility" strategy can be self adaptive to low, medium and high density environments. Thus rather than to change the metrics according to the network dynamic it is simpler to adopt this strategy.

4.2.2. Backbone parameter

For the second example of adaptation, the MPR selection in OLSR protocol, three strategies are also considered.

- 1*D*, is the basic OLSR selection strategy, a selection is done from one (1) criterion, the density (*D*),
- 1*D* + 2D, there is at first (1) the density criterion (D) and, in case of equality, at the second (2), the mobility criterion (*LD*),
- 1*LD* + 2D link duration criterion (1*LD*) then density metric one (2D).

As for the previous source routing adaptation, metric strategies have been evaluated by simulation and results are synthesized in Fig. 9.

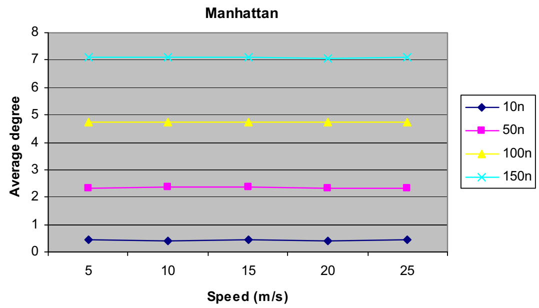
The obtained results are similar to those obtained with the CSR adaptation, although the number of nodes defining the low (10), medium (50), high (150) and very high (200) size of the networks differ, and even if, the mobility metric differs too; the number of Route Errors is used in CSR and the Link Duration is used in OLSR.

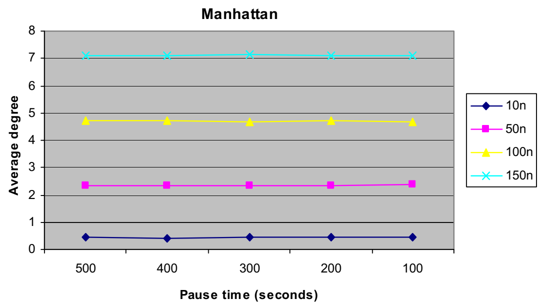
For small network, the mobility is more significant than the density but, when the number of nodes increases, the density metric becomes preferable and when the network still grows, the optimum strategy is the one that combines mobility and density. Furthermore, for all the cases of network size the strategy Mobility + Density is of interest. It performs quite close to the best strategies: Mobility for low density as well as to Density for medium density. Moreover, it has the best performance in high density network for which OLSR is well adapted. Thus, as previously 1*D* + *E* is the best strategy.

From performance results obtained on the two presented adaptations, it is shown that the metric choice is dependant of the network environment, but that it is possible to find a metric strategy helpful to improve the routing performance, whatever environment is. Moreover, a stable station in any network size may be characterized through its number of neighbors and by its mobility with regards to the graph connection.

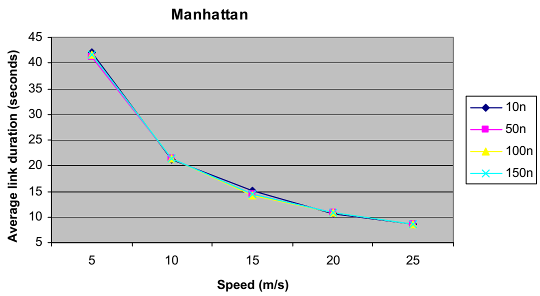
5. Impact of the mobility model

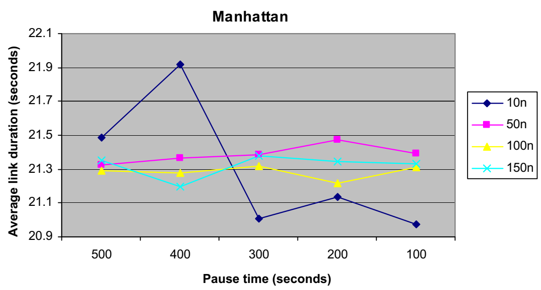
We discuss, in this section, the validity of the results when considering various mobility models. We analyze the metrics (*LD*, and *D*) while using three basic mobility models Manhattan (urban movement, over streets) [30], RPGM (group movement) [44] and Random WayPoint (individual movement) and various number of nodes (10, 50, 100, 150). Movement is composed of periods separated by a pause time, and a speed is associated to each period. Results are obtained with bonnmotion [45].





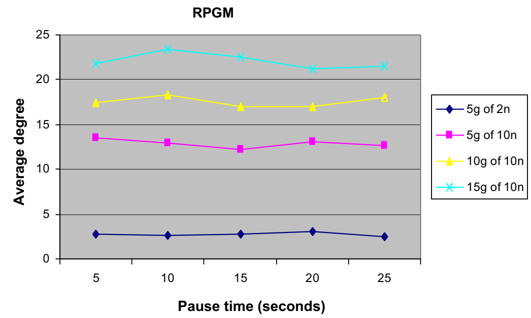
According to *Manhattan model*, the degree of terminals (number of neighbors) reveals the density of the network and is independent as well of the speed of the mobile as of the pause time.

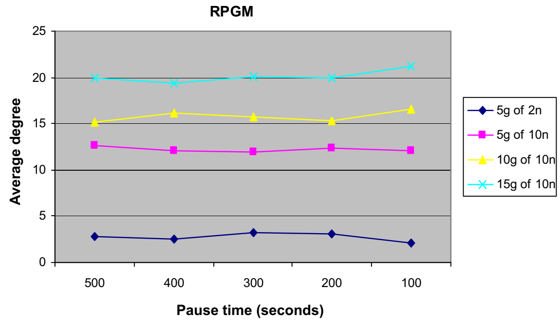




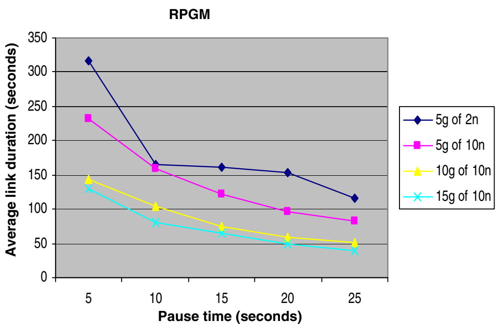
The average link duration, decreases exponentially according to the speed of the mobile, while it is insensitive to the pause time and to the density. Both metrics are independent of the pause time.

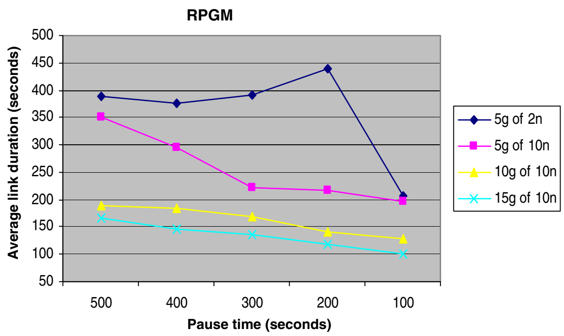
Now, consider the *RPGM model*. We realized simulations for respectively 10 (5 groups of 2 mobiles), 50 (5 groups of 10 mobiles), 100 (10 groups of 10 mobiles) and 150 (15 groups of 10 mobiles) mobiles.





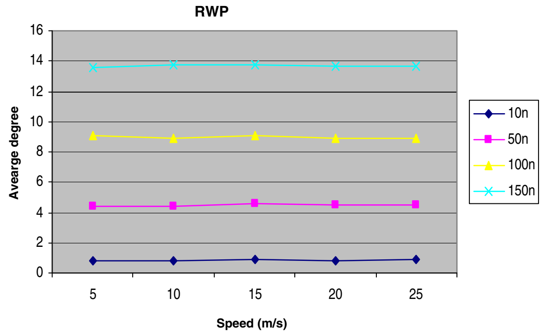
The movement in group limits asymptotically the mean degree of each node to the number of members in the group. This degree expresses the density of the network and is insensitive to the speed and to the pause time.

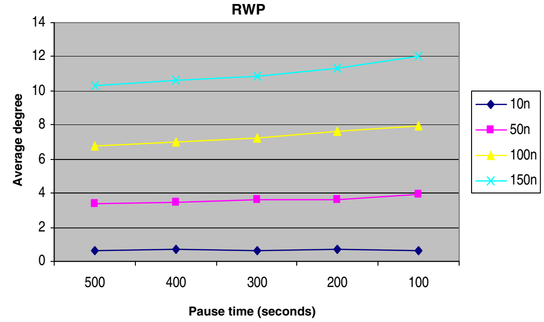




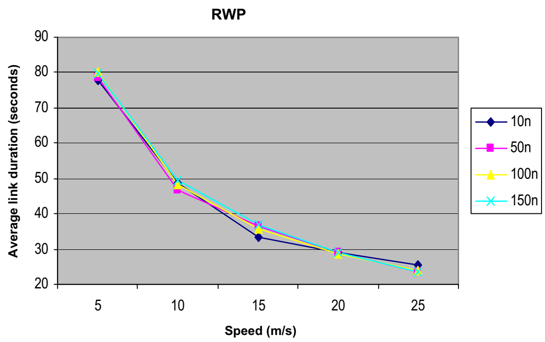
The link duration, decreases as a function of the speed. The standard deviation of this duration depends of the group size and of the density. We obtain the same result of the pause time.

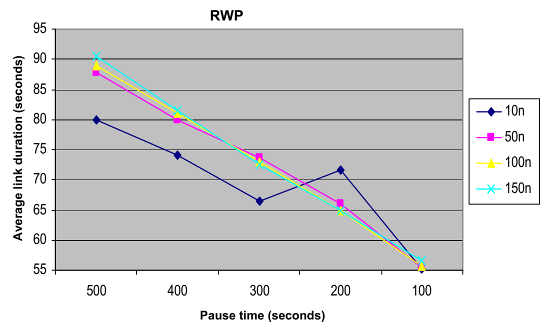
In *Random way point*, a complex relation between the speed and pause time exists. For instance, a scenario with fast mobile nodes and long pause times traduces a more stable network than a scenario with slow mobile nodes and short pause time.





Notice here, that the degree increases as a function of the density but it is independent from the speed. The results show that it slightly goes down as a function of pause time.





The link duration, as for the two first models, decreases as a function of speed. The link duration obtained for RPGM is longer than those obtained for RWP. While the Manhattan model gives the shortest values. It has to be noted, that the average link duration decreases linearly as a function of the pause time and is independent of the density.

Let us notice, that the metrics remain constant, as a function of pause time, only in the case of the Manhattan model. We may than conclude that this result is obtained for predictive models. Using those metrics may reveal the nature of the movement (predictive or not). Consequently, we may use those metrics to adapt mechanisms to the mobility.

We calibrated the NS2 simulation duration and warm up period, on the random way point model by correlating the link duration to the routing performances. We traced the link duration for routing protocols. We computed confidence interval for several scenarios, they was less to 10%, for a confidence level of 95%. On 1000 s we started the measuring after a 500 ms warm up period. For OLSR we compared results on few scenarios with 1000 s and 250 s. There was similar so we adopted 250 s.

6. Conclusion

The paper proposes a synthesis of works on dynamic routing for wireless and mobile networks. It classifies these works in function of the objective of the adaptation: power, transmission quality, traffic and topology; then it reviews the different way to take into account the network context. Furthermore, it characterizes the various options for the achievement of the protocol adaptation.

The presented work treats an original problem about the right representation of the network context: the one that would make efficient the adaptation. The adaptations proposed by literature are evaluated with only one chosen metric. In this paper, we consider the metric choice influence. We focus on the network context reflecting the topology dynamic. To represent it, two aspects are considered that are the node mobility and the network density. Several papers have studied them separately, we propose a novel approach combining the two aspects. It studies the impact as well of mobility as of density on the adaptation performance.

We propose different metrics for the topology change quantification. The density metric is locally measured by each node as its number of neighbors. Concerning the mobility, it depends on the protocol to adapt, as illustrated by the two examples we developed along the paper. The first example is an adaptation of the DSR protocol and the second adapts the OLSR protocol. For OLSR adaptation, the link duration mobility metric is introduced during the MPR selection process, while for DSR adaptation which aims to establish a clustering structure, the number of path failure is the used metric. These metrics are simple; available in each studied protocol and efficient; signaling minimizing and no extra protocol modification.

In order to assess whether the mobility metric is more influential than the density one and thus more captured of topology, case studies on several representation of topology change are compared. The simulation results highlight that the mobility metric has more impact in low density as well as the density is more important in medium density. For low density it is better to choose a node that does not move too rapidly in order to favor the graph connection. For high density, the density prevails over the mobility. It is preferable to choose a node with a lot of neighbors, because when it moves it is able to reconnect rapidly to the network graph. In sparse network, the mobility has a positive effect on connectivity, whereas in dense network the situation becomes the opposite. Nevertheless, it is found that first to adapt from the density metric then in equality event to adapt from mobility metric, significantly improves the protocol performance in all the density cases.

It has been shown that the context representation is a key point of the dynamic routing and that it has to be carefully studied. The method proposed in this paper is generic; it is suitable to different adaptations and node movements.

References

[1] S. Carson, J. Macker, Mobile Ad hoc Networking (MANET) : routing protocol performance issues and evaluation considerations. RFC2501, 1999.

[2] C. Perkins, E. Belding-Royer, S. Das, Ad hoc on-demand distance vector (AODV) routing, RFC 3561, 2003.

[3] T. Clausen, P. Jacquet, Optimized link state routing protocol (OLSR), RFC3626, 2003.

[4] R. Ogier, F. Templin, M. Lewis, Topology broadcast based on reverse-path forwarding routing protocol (TBRPF), RFC3684, 2004.

[5] D. Johnson, D. Maltz, Y. Hu, The dynamic source routing protocol for mobile ad hoc networks (DSR), RFC 428, 2007.

[6] S. Singh, M. Woo, S. Raghavendra, Power-aware routing in mobile ad hoc networks, in: ACM/IEEE International Conference on Mobile Computing and Networking, 1998.

[7] C.K Toh, H.Cobb, D.Scott, Performance evaluation of battery-life-aware routing scheme for wireless adhoc networks, in: IEEE International Conference on Communications (ICC), 2001.

[8] A.Misra, S.Banerje, MRPC: Maximizing network lifetime for reliable routing in wireless environments, in: IEEE Wireless Communications and Networking Conference, 2002.

[9] R.J. Punnoose, P.V. Nikitin, J. Broch, D.D. Stancil, Optimizing wireless network protocols using real-time predictive propagation modeling, in: IEEE Radio and Wireless Conference, 1999.

[10] R. Dube, C.D. Rais, K.-Y. Wang, S.K. Tripathi, Signal stability-based adaptive routing (SSA) for ad-hoc mobile Networks, IEEE Personal Communications 4 (1997) 36–45.

[11] C-K. Toh, Associativity-based routing for Ad-Hoc Mobile Networks, Wireless Personal Communications, International Journal 4 (2) (1997) 103–139.

[12] G. Lim, K. Shin, S. Lee, H. Yoon, J.S. Ma, Link stability and route lifetime in ad-hoc wireless networks, in: International Conference on Parallel Processing Workshops (ICPPW), 2002.

[13] D.S. Couto, D. Aguayo, J. Bicket, R. Morris, A high throughput path metric for multi hop wireless routing, in: International Conference on Mobile Computing and Networking (MobiCom), 2003.

[14] Q. Pang,V. Leung, S. Liew, A rate adaptation algorithm for IEEE 802.11 WLANs based on MAC-layer loss differentiation, in: Second International Conference on Broadband Networks, 2005.

[15] G. Holland, N. Vaidya, P. Bahl, A rate-adaptive MAC protocol for multi-hop wireless networks, in: International Conference on Mobile Computing and Networking (MobiCom), 2001.

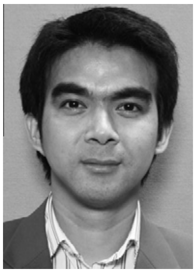
[16] S.-J. Lee, M. Gerla, Dynamic Load-Aware Routing in Ad-hoc Networks, in: IEEE International Conference on Communications (ICC), 2001.

[17] H. Hassanein, A. Zhou, Routing with Load Balancing in Wireless Ad-hoc Networks, in: ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWIM), 2001.

[18] X. Wang, S. Tagashira, S. Fujita, FDAR: A Load-Balanced Routing Scheme for Mobile Ad-Hoc Networks, Ad-Hoc, Mobile, and Wireless Networks, (ADHOC-NOW), 2007.

[19] Z.J. Haas, M.R. Pearlman, The performance of query control schemes for the zone routing protocol, IEEE/ACM Transactions on Networking (4) (2001) 427–438.
[20] S. Giannoulis, C. Katsanos, S. Koubias, G. Papadopoulos, A hybrid adaptive routing rotocol for ad hoc wireless networks, in: IEEE international workshop on factory communication systems, 2004.
[21] F. Jaddi, B. Paillassa, An adaptive hierarchical extension of the DSR: the cluster source routing, in: Journal of Universal Computer Science, vol. 13, No. 1, John Wiley and Sons, 1997, pp. 32–55.
[22] H.L. Seba, ARPM: An Adaptive Routing Protocol for MANETs, in: ACS/IEEE International Conference on Pervasive Services, 2006.
[23] S. Anh, A.U. Shankar, Adapting to route-demand and mobility in ad hoc network routing, Computer Networks: The International Journal of Computer and Telecommunications Networking 38 (6) (2002) 745–764.
[24] M. Benzaid, P. Minet, K. Alagha, Integrating fast mobility in the OLSR routing protocol, in: IEEE Conference in Mobile and Wireless Communications Networks, 2002.
[25] Z. Li, Y. Zhao, Y. Cui, D. Xiang, A density adaptive routing protocol for large-scale ad hoc networks, in: Wireless Communications and Networking Conference (WCNC), 2008.
[26] J. Li, P. Mohapatra, Laker: location aided knowledge extraction routing for mobile ad hoc networks, in: IEEE Wireless Communications and Networking conference, (WCNC), 2003.
[27] R. Knopp, N. Nikaein, C. Bonnet, H. Aiache, V. Conan, S. Masson, G. Guibe, C.L. Martret, Overview of the widens architecture, a wireless ad hoc network for public safety, in: IEEE International Conference on Sensor and Ad Hoc Communications and Networks (SECON), 2004.
[28] S. Charoenpanyasak, B. Paillassa, F. Jaddi, Experimental study on TCP enhancement interest in ad hoc networks, in: International Conference on Wireless and Mobile Communications (ICWMC), 2007.
[29] Cholatip Yawut, B. Paillassa, R. Dhaou, Mobility metrics evaluation for self-adaptive protocols, Journal of Networks 3 (1) (2008) 53–64.
[30] F. Bai, N. Sadagopan, A. Helmy, Important: a framework to systematically analyze the impact of mobility on performance of routing protocols for adhoc networks, in: Joint Conference of the IEEE Computer and Communications Societies (INFOCOM), 2003.
[31] Wei-Jen Hsu, T. Spyropoulos, K. Psounis, A. Helmy, Modeling spatial and temporal dependencies of user mobility in wireless mobile networks, IEEE/ACM transaction on networking 17 (5) (2009) 1564–1577.
[32] L. Qin, T. Kunz, Mobility metrics to enable adaptive routing in manet, in: IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, (WiMob), 2006.
[33] P. Johansson, T. Larsson, N. Hedman, B. Mielczarek, M. Degermark, Scenario-based performance analysis of routing protocols for mobile ad-hoc networks, in: ACM International conference on Mobile Computing and Networking (MobiCom), 1999.
[34] Y.C. Tseng, Y.F. Li, Y.C. Chang, On route lifetime in multihop mobile ad hoc networks, IEEE Transactions on Mobile Computing 2 (4) (2003) 366–376.
[35] A.B. McDonald, T. Znati, A path availability model for wireless ad-hoc Networks, in: IEEE Wireless Communications and Networking Conference (WCNC), 1999.
[36] J. Haerri, F. Filali, C. Bonnet, On the application of mobility predictions to multipoint relaying in MANETs: kinetic multipoint relays, Eurecom Technical Report, Institut Eurecom, 2005.
[37] W. Su, S.-J. Lee, M. Gerla, Mobility Prediction in Wireless Networks, in: IEEE Military Communication Conference (MILCOM), 2000.
[38] J. Boleng, W. Navidi, T. Camp, Metrics to enable adaptive protocols for mobile ad hoc networks, in: International Conference on Wireless Networks (ICWN), 2002.
[39] S. Obilisetty, A. Jasti, R. Pendse, Link stability based enhancements to OLSR (LS-OLSR), in: Vehicular Technology Conference (VTC), fall 2005.
[40] D. Johnson, D. Maltz, Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, Kluwer, 1996.
[41] The Network simulator-ns-2, 2011, (<http://www.isi.edu/nsnam/ns/>).
[42] J. Broch, D. Maltz, D. Johnson, Y-C. Hu, J. Jetcheva, A performance comparison of multihop wireless adhoc network routing protocols, in: ACM/IEEE Mobicomm, 1998.
[43] T. Clausen, P. Jacquet, L. Viennot, comparative study of routing protocols for adhoc network, IFIP MedHocNet, 2002.
[44] X. Hong, M. Gerla, G. Pei, C. Chiang, A group mobility model for ad hoc wireless networks, in: ACM/IEEE MSWIM, 1999.
[45] Univ of bonn, bonnmotion : a mobility generation and analysis tool, 2011 (<http://www.net.cs.uni-bonn.de/fileadmin/ag/martini/projekte/BonnMotion/src/BonnMotion_Docu.pdf)>.

Beatrice Paillassa is Professor in computer networks at the ENSEEIHTT engineer school. She earned a doctorat in computer sciences and an habilitation in computer networks from Toulouse university. Member of the research team IRT " Network and Telecommunication Engineering" at the IRIT laboratory (UMR CNRS 5505) of Toulouse, her research interest includes communication protocols design and analysis, modelling, and architecture specification. She currently works on adaptive protocols for wireless networks, in particular routing protocol, transport protocol and mobility metrics for ad hoc networks



Cholatip YAWUT is currently assistant at the Faculty of Information Technology, King Mongkut's University of Technology North Bangkok, Bangkok–Thailand. He received his Master of Science in Information Technology from King Mongkut's Institute of Technology North Bangkok, Thailand, 2003, Master of Research in Networks, 2005, and a doctorat from the INPT-ENSEEIHT in 2009.

Riadh DHAOU has been appointed Assistant Professor at the Telecommunication and Networking Division of the INPT/ENSEEIHT (Institut National Polytechnique de Toulouse). Since September 2003, he is a member of the IRT team of the IRIT Lab. (CNRS-UMR 5505) and of TéSA Lab.
He received the "Diplome d'Ingenieur Concepteur en Informatique" from the cole Nationale des Sciences de l'Informatique (ENSI), University of Tunis II in 1997, and the Diplome d'Etudes Approfondies (D.E.A.) in Computer systems from the Université Pierre et Marie Curie in Paris (Paris VI), in 1998. In November 2002, he was awarded Ph.D. degree in Computer Systems, Telecommunication and Electronic by the University of Paris VI.
His research interests include statistical characterisation and modelling of mobility, mobile and space communications, cross layer schemes modelling and optimisation, performance analysis of wireless networks, autonomous multi-hop/cooperative communications systems, capacity and outage analysis of multi-user heterogeneous wireless systems, resource allocation, design and performance evaluation of wireless sensor networks and energy consumption optimisation.