Mobility Metrics Evaluation for Self-Adaptive Protocols

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***Abstract*—Cross-layer mechanism, for which a protocol locating at a given layer uses information issued from other layers, may enhance the mobile networks performance. Some of those mechanisms are based on mobility metrics. For example, the establishment of a route by choosing less mobile nodes could improve the routing protocol. In this paper, we study the ability of mobility metrics to reflect the mobility influence over the protocol performances. The proposed approach evaluates the ability of a metric from its capacity to indicate or predict the routing protocol performance. Three routing protocols are considered: AODV, DSR and OLSR. The studied mobility metrics are Frequency of Link State Changes (LC), Link Connectivity Duration (LD) and Link Stability Metric (LS). The metrics are evaluated by simulation, firstly in a general case then in a scenario case.**

***Index Terms*— Mobility Metric, Ad hoc, Routing Protocols**

I. Introduction

We study the mobility metrics for mobile networks, such as mesh or ad-hoc networks. A mobile network must effectively react to the topological changes and to the traffic demands by maintaining an effective routing. The nodes are free to move, the topology of the network may change randomly and quickly. We show in [1] the interest of a mobile self adaptive routing protocol over such environment. In a similar way, others protocols would be enhanced by knowing the *"less"* mobile element. So, an important question is: how to describe the mobility in order to manage the mobile networks effectively?

In [2], we present a synthesis of mobility metrics and specify the functions, which they influence. Previous works with quantitative study have been intended either to analyze the mobility models, or to compare protocols performance. For example, comparison between protocol performances related to the mobility metrics in the Random Waypoint [3] model are performed in [4-8]. Many studies [6-18] investigate in the relationship between the mobility metrics and the mobility models. [15] evaluates the impact of the metric over the mobility model then the impact of the mobility model over the routing protocol performance.

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The aim of our experimental study is to determine the behavior of different mobility metrics rather than the protocol behavior and to appreciate the 'good' value of a metric.

Characteristics of a good mobility metric, as given in [7], are: computable in a distributed way without global network knowledge, able to indicate or predict the protocol's performance, feasible to compute (in terms of node resources), independent of any specific protocol and computable in real network without any simulation artifact.

We study three metrics that do not require global network knowledge and are feasible to compute. By simulation, we evaluate their ability to indicate or predict the protocol performance whatever the used routing protocol and network conditions.

This paper is organized as follows: section 2 presents mobility metrics synthetic, section 3 summarizes the considered mobility metrics, section 4 describes the parameters that are tackled for the evaluation by simulation, section 5 highlights the results that are obtained for different MANETs routing protocols. Firstly, we consider a general model then we focus on a specific scenario.

II. Mobility Metric Synthetic

We classify metrics from the brought information. Those metrics may be obtained from different levels (i.e. at physical, logical link, and network levels). This section firstly presents some metrics jointly obtained at network and logical link layers. Secondly, metrics obtained at separate layers such as network, logical link, and physical layers are presented. Finally, we address inter-layer metrics at physical and logical link layer.

A. Inter-layer Network/LLC/MAC Metrics

1. Path availability $\Pi_{m,n}^{k}(t)$

This metric depends on the *link availability*, $A_{m,n}(t)$ between two nodes; *m* and *n*. It is defined as follows in [9]:

$$\Pi_{m,n}^{k}(t) = \prod_{i,j \in k} A_{i,j}(t) \quad (1)$$

Where k is the path (of which one seeks to know the availability). This metric makes it possible to know the availability of a path between two nodes m and n. However, this metric (in this definition, others are possible/ through measurements for instance) does not make it possible to know exactly the availability of the paths of the network and consequently cannot induce a reaction of the network. Nevertheless, if the probabilities of the link availability are well defined, this metric makes it possible to have an important knowledge of the performance of the network and mobility of the nodes. The motivations of this metric are clarified in the paragraph devoted to *link availability.*

B. Intra LLC/MAC layers Metrics

1. Number of neighbours' nodes

This metric is defined in [8] as being the number of neighbours i.e. the number of nodes within the range of the transmission of the considered node. It makes it possible to have information on the density of the network the local variations of this density (what inevitably does not have a direct impact on the other metrics like the connectivity of the links). This metric is utilised mainly in the case of an aggregation of information of different nodes and may have an influence on the choice of the routes.

The principal interest of this metric is that its calculation does not require almost any cost overrun for the node. Consequently, it can be used relatively simply (possibly locally) in the choice of the routes without causing consequent routing overhead or important calculative cost.

2. Link availability $A_{m,n}(t)$

This metric defined in [9] represents the availability of a link:

$$A_{m,n}(t) = Pr(L_{m,n}(t_0 + t) = 1 \mid L_{m,n}(t_0) = 1) \quad (2)$$

Where, $L_{m,n}(t) = 1$ means that the link is active. It is the probability that the link is active at the moment $t_0 + t$ given that it is active at the moment t_0. This metric, as well as the path availability, as developed in [9], makes it possible to choose the most stable links when the routes is established, and thus to reduce the ruptures of routes, and consequently to reduce the routing overhead being able to represent an important proportion of the traffic on a mesh network. Moreover, the calculation of routes consumes resources on the hosts, which in a mobile network are generally materials whose resource must be saved (portable, mobile telephones...). These metrics thus allow an economy of the resources initially carrying out the good choice of link and route.

3. Enhanced link availability $A^T_{m,n}(t)$

The *enhanced link availability* metric is defined as follows in [10]:

$$A^T_{m,n}(t) = A^i_{m,n}(t)P_i + A^c_{m,n}(t)(1 - P_i) \quad (3)$$

Where $A^i_{m,n}(t)$ represents the *link availability* when the nodes have independent movements, $A^c_{m,n}(t)$ represents the *link availability* when the nodes have correlated movements, P_i is the probability that the nodes have independent movements, and T means total.

When the model considers the set of nodes with independent movements, as the *link availability* which is related to the probability of activity of the links, the evaluated connectivity of a link between two nodes is less important than it is in reality. Some nodes thus present a correlation in their movements (two people exchanging directly knowingly a file for example). Consequently, a new metric of availability of the link is interesting, taking into account the possible correlation of the movements of the nodes: it is the *enhanced link availability*.

The practical evaluation of this metric raises two problems: the evaluation of P_i and that of $A^c_{m,n}(t)$. Authors, in [10], have proposed a method of calculation of $A^c_{m,n}(t)$ increasing its value according to the duration of activity of the link (active link). On the other hand, the same authors do not propose a method of calculation of the probability of correlation P_i but make only recommendations on which should be the value (large or small) of P_i according to the context of the network (vehicular, pedestrians,...).

4. Link duration T^i_c

As it is defined in [11], lets use the connectivity between 2 points i and j at the moment t:

$$T^i_c(i, j, t) = e^{-\alpha v(i,j,t)} \quad (6)$$

Where α is a constant and $v(i, j, t)$ is the relative speed of the nodes i and j at t. Let n_d be the number of nodes, the average duration of the connectivity $\overline{T^i_c}$ of a node i during the time T_m is:

$$\overline{T^i_c} = \int_0^{T_m} \frac{1}{n_d} \sum_j^{n_d} T_c(i, j, t)\,dt \quad (7)$$

This metric considers the problem of the availability, the time, which the transmitter will be able to transmit indeed. An metric of mobility is thus the time of connectivity, or duration of the link, T^i_c. This parameter indicating the availability (of connectivity) of a node can thus be useful not only at the time of the decision of a route and thus on the level of the performance of the routing protocols but also for the choice of the routing protocol to be used.

However, it does not reflect the frequency of the changes of state of the link (possible transmission or not) in particular, if the duration of the state *off* of the link is lower than the duration of expiry of the routes T_c^i remains unchanged.

5. Link change rate, Link state changes λ_{lc}

The frequency of the changes of state of the link λ_{lc}. is called *link change rate* in [7] and *link state changes* in [11]. For a model Random Waypoint (RWP), a typically used model in the evaluation of mobile networks, [12] shows that λ_{lc} can be defined like the reverse of the period during which the transmission is possible then becomes impossible.

$$\overline{\lambda_{lc}} = \frac{1}{\overline{T_{lc}}} \tag{8}$$

In literature, the principal objective of this metric is to be able to carry out a comparison between the results of various studies on different models, different problems having this common global mobility characteristic. Thus, the suggested solutions (for the routing, the link layer and the time of existence of a route in a table) can be simulated on various models and can be concretely tested with the insurance that the network always has the same mobility. The obtained results will be thus more coherent and comparable. In [13], the metric is used to evaluate a new mobility measure, the remoteness.

[7] initially aims to create a standardized environment to study the performance of various MANET protocols uses the *link change rate* to observe the frequency of the changes of state of the link, aspect untreated by the *link duration*. The disadvantage is that it does not make it possible to have a global vision of the availability of a node, for example by the longevity of the link, and thus does not allow evaluating the effect of the link state changes on the transmission. Illustration of this disadvantage is given in [11].

6. Link stability metric L_s

[11] introduces a parameter using the *average link duration* and the *link state changes* by combining their advantages.

$$L_s = \frac{\overline{T_c}}{\lambda_{lc}} \tag{9}$$

According to [10], neither λ_{lc}, nor T_c^i can describe correctly the mobility concerning the Random Waypoint model. Indeed, the increase of the maximal speed does not disturb T_c^i but increase λ_{lc}. On the other hand, T_c^i increases at the same time as the range of a node whereas λ_{lc} is insensitive to this range. It was thus necessary to introduce a new parameter L_s taking into account simultaneously with all these characteristics related to the mobility of the network. This parameter is then sensitive at the same time to the duration of connectivity and the frequency of changes of the state of the links. These two parameters react to two different problems related to a wireless transmission (non-connectivity and too frequent changes of the state of the link). They are complementary and gathering them in the same parameter allows to fill their weakness.

It is shown in [12] that for random way point model the link stability is the best metric. This conclusion is based on the mobility representation capacity rather than on protocol performance. Authors show that link stability metric reflects well the random way point mobility model. In this paper, we evaluate differently the "good" properties of this metric.

C. Inter-level Metrics LLC/MAC/physical

1. Local mobility metric

This metric defined in [14] is based on the received power, by a node Y, at the time of the emission of a "hello" message, by a station X considered in its entourage.

Let us note $RxPr_{X\to Y}$ the received power, by the node Y, at the time of the reception of a "hello" message coming from X. Then the relative mobility of Y compared to X is written:

$$M_Y^{rel}(X) = 10\log\frac{RxPr_{X\to Y}^{new}}{RxPr_{X\to Y}^{old}} \tag{10}$$

Thus, if $M_Y^{rel}(X) < 0$ this means that the nodes move away and if $M_Y^{rel}(X) > 0$ they approach.

One then carries out the aggregation of the whole of these metrics of the partial mobility of Y compared to his neighbours in order to give a local mobility criterion of Y in the environment which surrounds it (its close nodes).

$$M_Y = Var_0\left[M_Y^{rel}(X_j)\right]_{j=1}^m = E\left[\left(M_Y^{rel}\right)^2\right] \tag{11}$$

Where X_1......X_m are the set of neighbours of Y. The obtained metric thus gives an indication on the mobility of the node Y compared to its close environment (a small value of M_y indicates a low mobility compared to its neighbours). The problem consists in determining which nodes are considered as being in the entourage of Y. This last parameter makes it possible to vary the significance of the metric and to give him a more or less local relevance.

This type of metric can be used to determine trees of covering because it makes it possible to determine which node from the different nodes of the area is the least mobile (compared to its neighbours) and thus to determine the nodes most likely to maintain a strong connectivity with its neighbours.

This measurement is based however on the received power and is thus dependent on the quality of the transmission. Nevertheless, the use which is made by it is relatively dynamic and the transmission medium can be regarded as relatively stable in general over short periods of time (which is the case). It is thus rather independent of the quality of the medium (but not of its variation if this one is sudden).

D. Physical level Metrics

1. Mobility measure $M(t)$ (using the Remoteness Concept)

The ***remoteness*** concept in [13] consists in the definition of a function $F(d_{ij}(t))$ of the distance between 2 nodes *i* and *j*. This function expresses several observations:

- The remoteness between 2 nodes which are located at the same place is 0. If the nodes are separated from each other by an infinite distance, their remoteness is 1.

$$F(0)=0, \lim F(x)=1 \tag{12}$$

- The remoteness increases with the distance.

$$\frac{d}{dx}F(x)\geq 0 \ \text{ for all } x\geq 0 \tag{13}$$

- For a node having a communication range R, a node located at a distance of 3R can be considered as remote as a node located at a distance of 10R.

$$\lim_{x\to\infty}\frac{d}{dx}F(x)=0 \tag{14}$$

- In a similar way, if a node is at a distance quite lower than R, its remoteness will not vary so much even if its distance is doubled.

$$\frac{d}{dx}F(x)|_{x=0}=0 \tag{15}$$

- If a node is at a distance close to R, its remoteness will vary tremendously, according to, if it approaches or if it moves away.

$$\frac{d}{dx}F(x)|_{x=R}\geq\frac{d}{dx}F(x)\forall x\geq 0 \tag{16}$$

A function $F(x)$ satisfying these conditions is:

$$F(x)=\frac{1}{\Gamma(r)}\int_0^x \lambda e^{-\lambda\tau}(\lambda\tau)^{\tau-1}d\tau, x\geq 0, \tau\geq 2 \tag{17}$$

The *mobility measure* is defined like the derivative of the *remoteness* with respect to time:

$$M(t)=\frac{1}{N}\sum_{i=0}^{N-1}M_i(t) \tag{18}$$

Where N is the number of nodes and $M_i(t)=\frac{1}{N-1}\sum_{j=0}^{N-1}\left|\frac{d}{dt}F(d_{ij}(t))\right|$

It is shown by various simulations in [13] that this flexible metric predicts well the changes of state of the link, as the *link change rate* metric.

Meanwhile the computation of this metric has to be done with a global knowledge of the network.

2. Degree of spatial dependence

This metric describes if two nodes move overall in similar directions. As defined in [15]:

$$D_{spatial}(i,j,t)=RD\left(\vec{V}_i(t),\vec{V}_j(t)\right)*SR\left(\vec{V}_i(t),\vec{V}_j(t)\right) \tag{19}$$

Where $RD(\vec{a},\vec{b})=\frac{\vec{a}.\vec{b}}{|\vec{a}|*|\vec{b}|}$ represents the cosine of the angle between a and b and $SR(\vec{a}(t),\vec{b}(t))=\frac{min(|\vec{a}(t)|,|\vec{b}(t')|)}{max(|\vec{a}(t)|,|\vec{b}(t')|)}$ represents the ratio of the speeds between the two vectors.

This metric generates another one: the average degree of space dependence. It is the arithmetic average of the degree of dependence on the whole set of pairs of nodes of the network and over time.

$$AD_{spatial}=Moy_{paires,t}\left(D_{spatial}(i,j,t)\right) \tag{20}$$

This last metric makes it possible to determine if the nodes of the network have a strongly correlated movement or not. Indeed, if the nodes move overall in the same direction and at the same speed then $AD_{spatial}$ is large, on the contrary, if the nodes have a completely random movement, the ones compared to the others this metric will be very small (or null).

The evaluation of these metrics is studied by simulation. Their value is plotted as a function of the maximum speed for various mobility models (RPGM, Freeway, Manhattan and Random Way Point model). Authors consider that the metric is useful as it differentiates the mobility models.

3. Degree of temporal dependence

This metric describes if a node moves in the same direction and at comparable speeds between two moments [15].

$$D_{temporal}(i,t,t')=RD(\vec{V}_i(t),\vec{V}_i(t'))*SR(\vec{V}_i(t),\vec{V}_i(t')) \quad (21)$$

Where RD and SR have the same definition as in the preceding paragraph.

The degree of spatial dependence is the average of this metric, which is really interesting: the average degree of temporal dependence is the arithmetic average of $D_{temporal}(i, t, t')$ on the set of the tuples (*i, t, t'*).

$$AD_{temporal}=Moy_{(i,t,t')}\left(D_{temporal}(i,t,t')\right) \quad (22)$$

This metric makes it possible to determine the degree of variation of the speed and direction of a node over time. If the speed and the direction are less correlated over time, this metric will take a low value and conversely.

4. Relative speed

This metric [16] defines the relative speed between two nodes.

$$RS(i,j,t)=\left|\vec{V}_i(t)-\vec{V}_j(t)\right| \quad (23)$$

In the same way, the *Average Rrelative Speed* is defined as the average on the set of the tuples (*i, j, t*) relative speeds of the nodes.

$$ARS(i,j,t)=Moy_{(i,j,t)}\left(RS(i,j,t)\right) \quad (24)$$

This metric brings an indication on the dynamics of the network, i.e. of the nodes, the ones with respect to the others.

This metric is relatively simple and natural (even if it requires a positioning system); it can locally be used to privilege a neighbour rather than another in the establishment of a route because its behavior (its relative speed) will make it a stable neighbour.

From simulations, authors in [15] indicate that the Average Degree of Temporal Dependence does not differentiate between various mobility patterns, while Average Relative Speed succeeds.

5. Mobility by the probability of link changes: D(t)

The general mobility metric, called *DTP* mobility or *D(t)*) in [17], represents a good approach to characterize the mobility because it detects the changes of topology of the network thanks to the quantification of the changes of connectivity of this last. *D(t)* is defined as the generalization of the mobility at the moment *t* of an ad-hoc network with the supposed entropy of a change of link at the time *t+1* giving the state of the link at the time *t*.

$$D(t)=\frac{2}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}D_{ij}(t) \quad (25)$$

Where $D_{ij}(t)$ is the required information to describe the change of the state of the link between the nodes *i* and *j*:

$$D_{ij}(t)=-\{q_{ij}(t)\log(q_{ij}(t))+[1-q_{ij}(t)]\log(1-q_{ij}(t))\} \quad (26)$$

With $q_{ij}(t)=\frac{q_{ij}^{u}(t)+q_{ij}^{d}(t)}{2}$ the probability of a change of the state of a link (up towards down and conversely) characterized by the probabilities of the links up and down of the link between nodes *i* and *j* at the moment *t* which are respectively:

$$q_{ij}^{u}(t)=Pr\{m_{ij}(t+1)=1/m_{ij}(t)=0\};\ i,j=1,2,..,N \quad (27)$$

$$q_{ij}^{d}(t)=Pr\{m_{ij}(t+1)=0/m_{ij}(t)=1\};\ i\neq j \quad (28)$$

Where $m_{ij}(t)=1$ if there is a direct link between *i* and *j* and $m_{ij}(t)=0$ if not.

For a network that is observed for a continuous period of time *T*, the average on *T* of *D(t)* may be used to characterize the mobility of the network.

$$D=\frac{1}{T}\int_{t_0}^{t_0+T}D(t)dt \quad (29)$$

D(t) presents some characteristics that are described in the following paragraph. It appears that the simulation results with the various mobility models (Random WayPoint, Manhattan and Battlefield,) extracted from [17], confirm these characteristics. In more detailed way, it is noted that *D* increases when the speed of the nodes increases, *D* reflects the changes of topology of the network exactly in the same way, whatever the used model of mobility. Moreover, *D* decreases when the average link duration increases.

The changes of state of a link (i, j) due to the mobility act on the value $m_{ij}(t)$. Thus, more the value of $m_{ij}(t)$ changes more the level of mobility is important. However, the number of changes (related to the used model) of $m_{ij}(t)$ does not make it possible to reach easily the level of mobility of the network with various numbers of nodes. This is why the *link change rate* is not a general metric because it depends on the model of the studied network whereas the *probability of the link change rate* remains independent of the used model. This is why the seek for a general metric *D(t)*, calculated from the probability of the link change rate. It must thus answer certain requirements which are as follows:

- It must describe the changes of topology of the network;

- It must be independent of the used model of mobility;
- It must be independent of the number of nodes.

Main use of DTP is for routing protocol comparison without worrying about the used model and the importance of the network. Indeed, the DTP mobility is opposed to relative metrics to a particular model of mobility like the *average link duration* or the *link change rate.*

E. Multi-levels Metrics LLC/MAC - Physical

1. The concepts of Contact and of Encounter

These two concepts are defined in [18].

An *encounter* e_{nm} between 2 nodes occurs when their distance is lower than the range of the nodes. This encounter is represented by the moment when it occurs and the time of its duration:

$$e_{nm} = \{n, m, t, \Delta t\} \tag{30}$$

A *contact* is the list of the *encounters* between 2 nodes:

$$c_{nm} = \{e_{nm}\} \tag{31}$$

Let us note C_n the set of the *contacts* of a node *n* during time T (the observation period):

$$C_n = \{c_{nm}\} \tag{32}$$

Let us note E_n the set of the *encounters* of a node *n* during the time T:

$$E_n = \{e_{nm}\}_{\forall m \neq n} \tag{33}$$

The mobility increases the capacity of a network and helps to overcome its partitioning. In order to benefit from the mobility of a node, a new class of MANET protocols and applications were studied in order to be tolerant to the delay and to profit from the mobility. To arrive to this, the mobility on a long scale of time must be taken into account. However, up to now, MANET considered the mobility only over a short time.

This is why, [18] introduced the new concepts of *contact* and of *encounter*, which makes it possible to build metrics quantifying the mobility on a long scale of time. In epidemiology, the *contacts* are very important for the analysis and the prediction of the diffusion of the infectious diseases.

Its authors put these questions:

- How much new contacts a node meets per unit of time?
- With which frequency 2 nodes do they meet?
- How long does an *encounter* remain established? Or how long does a *contact* remain lost?

These reflections bring to define several metrics:

- The ***Contact rate*** is the number of new contacts, of the node n, per unit of time: $ACR_n = \frac{|C_n|}{T}$. On a network, the *average contact rate* is defined as the average of ACR_n for N nodes:

$$ACR = \frac{1}{N}\sum_{n=0}^{N-1} ACR_n \tag{34}$$

- The ***Encounter frequency*** is defined by the number of *encounters*, made by the node n during the period T divided by the number of *contacts* of this same node during the period T: $AEF_n = \frac{|E_n|}{|C_n|}$. On a network, the *average encounter frequency* is defined as the average of the encounter frequency. This gives the average number of meeting per contact:

$$AEF = \frac{1}{N}\sum_{n=0}^{N-1} AEF_n \tag{35}$$

- The ***Encounter rate*** is the number of *encounters* of the node n per unit of time: $AER_n = \frac{|E_n|}{T}$. On a network, the *average encounter rate* is defined as the average of the *encounter rate*. This gives the average number of *encounters* made by a node per unit of time:

$$AER = \frac{1}{N}\sum_{n=0}^{N-1} AER_n \tag{36}$$

- The ***Average contact duration*** is the average duration of a contact for the node n, i.e. the average duration of the sum of its *encounters*, is defined by: $ACD_n = \frac{\sum_{e_{nm} \in E_n} e_{nm}.\Delta t}{|C_n|}$. On a network, the average *duration* of a contact is:

$$ACD = \frac{1}{N}\sum_{n=0}^{N-1} ACD_n \tag{37}$$

- The ***Contact loss duration*** is the average duration of loss of a contact is:

$$ACLD_n = T - \frac{\sum_{e_{nm} \in E_n} e_{nm}.\Delta t}{|C_n|} = T - ACD_n \quad (38)$$

- The ***Encounter duration*** is the duration of an *encounter* is: $AED_n = \frac{\sum_{e_{nm} \in E_n} e_{nm}.\Delta t}{|E_n|}$. On a network, the average duration of an *encounter* is:

$$AED = \frac{1}{N} \sum_{n=0}^{N-1} AED_n \quad (39)$$

The experimental work shows the following results:

- ACR varies linearly with the density of the nodes and with the maximum speed of the nodes
- AEF is independent of the density of the nodes and increases with the node max
- $AER \approx ACR * AEF$
- $ACD \approx AED * AEF$

Authors of [18] conclude from the statistical analysis, that the *average encounter frequency* plays a central part in the set of these metrics. Moreover, AEF, AED and ACD are independent of the density of the node whereas AER and ACR increase linearly with the density of the nodes.

In fact, this metrics would be considered as density metrics rather than mobility metrics.

III. Studied Metrics

The main idea is that protocol would change its algorithm according to the mobility so that it could improve network performance. Besides, for a low mobility the A1 algorithm is used as it well performs, but in case of high mobility, the A2 algorithm is applied since network performance are degraded with A1. Objective of the metric study is to evaluate their ability to be used for such protocol comportment. Easily to compute, the metric value has to be connected to the network performance.

Because they are easily computable, we study the following mobility metrics: Frequency of Link State Changes (LC), Link Connectivity Duration (LD) and Link Stability Metric (LS). Frequency of Link State Changes (LC) that related with section I-B-4 is the number of link state changes. When Node comes into the transmission range of another node, metric is increased by one indicating a link connection. When Node moves out of the transmission range, the metric is increased by one indicating link breakage. The average LC is done over the number of considered nodes.

Link Connectivity Duration (LD) that related with section I-B-3 indicates the period a link is in the transmission range of a determined node. Figure 1 depicts how to calculate LC and LD in network.

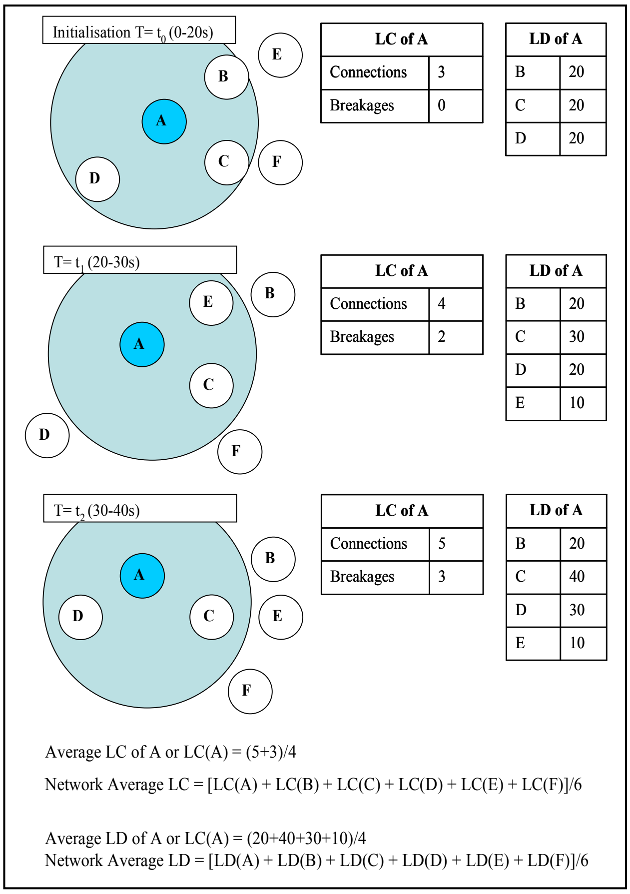
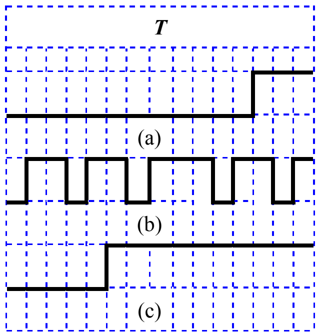


Figure 1. Example of average LC and LD calculation



	a	*b*	*c*
LC	1/T	9/T	1/T
LD	T/5	2T/3	2T/3
LS	$T^2/5$	$2T^2/27$	$2T^2/3$

(d)

Figure 2. Impact of mobility on three mobility metrics

Link Stability Metric (LS), which relate with section I-B-5, combines the information of both LD and LC. LS capture link longevity as well as frequency of link changes. It is defined as: LS = LD/LC.

Before the use of simulation for metric analysis, we present a non valued analysis. In [10, 11], the authors argue that LS is better than LC and LD. However, we do not consider LS as a *"good metric"* as explained it in Fig 1.

As shown in Fig 1-a and 1-c, LC of both cases is equal but the link duration is different. The routing protocol can work better in the case 1-c than in the case 1-a because of the long duration connectivity. LC in Fig 1-b is higher than in Fig 1-a. However, the routing protocol can perform better in Fig 1-b than in Fig 1-a because of the long duration connectivity which means that there is a route to the destination (if there is a route the protocol can find it). Hence, the average LC is not the best mobility metric.

LS can indicate LD as well as LC. Nevertheless, LS is not really a good metric because it depends on LC. According to Fig 1-d, the value of LS, it ordered by $2T^2/3$ (c) > $T^2/5$ (a) > $2T^2/27$ (b). It appears that LS in Fig 1-a is more stable than that in Fig 1-b. Indeed, the routing protocol can work better with LS in Fig 1-b than in Fig 1-a because of the long duration connectivity. Therefore, the average LS does not seem to be the best mobility metric.

As illustrated in Fig 1-b and Fig 1-c, LD in both cases is equal but the frequency of the link change is different. Network goodput can probably be good in two cases because of the long duration connectivity, but the overhead in Fig 1-b is higher than that in Fig 1-c because of the LC value.

LD in Fig 1-b is more stable than that in Fig 1-a, but it is higher too. However, the routing protocol can be more efficient in Fig 1-b than in Fig 1-a because of the long duration connectivity.

Hence, the average LD would be the best mobility metric among all three mobility metric.

IV. Parameters of evaluations

We use simulation to evaluate the capacity of metric to predict the protocol performance. We focus on routing protocols. The performance of AODV [19], DSR [20], and OLSR [21] according to UM-OLSR-0.8.8 [22] is compared by the different mobility metrics.

A. *Mobility models*

To study the effect of mobility on MANET protocol performances, Random Waypoint model (RWP), and Reference Point Group Mobility model (RPGM) [23] are used.

B. *Performance metrics*

Two performance metrics [3] are evaluated:

1) The packet delivery ratio (PDR) is the ratio of the data packets delivered to the destination to those generated by the CBR sources.

2) The normalized routing overhead is the number of "transmitted" routing packets per data packet "delivered" to the destination. Each hop-wise, transmission of a routing packet is counted (in bytes). The routing overhead includes: 1) Routing Protocol Overhead Packet (in byte) such as Route Request, Route Reply, Route Error, etc. 2) Routing Overhead on data packet (in byte) because the different routing protocol have different routing header, e.g. DSR has a variable header size upon the number of hops the packet traversed, AODV has fixed size header.

Routing overhead on data packet is calculated by the different between packet transmission (RTR) and packet Original (AGT).

Then, we calculate the normalized routing overhead = 100 * (Protocol Routing Overhead on data packet + Routing Protocol Overhead Packet)/(Packet Original (AGT) + transmitted on RTR).

C. *Simulation models*

Network simulator NS2.29 [24] is used with a simulation time of 1000s in an area of 1000m x 1000m.

Firstly, we consider general models. For RWP, we use 2 topologies: 10 nodes and 50 nodes. For RPGM, we use 5 groups of 2 nodes and 5 groups of 10 nodes, which are moving independently to each other and in an overlapping fashion. Both Speed Deviation Ratio (SDR) and Angle Deviation Ratio (ADR) are set to 0.1. The same check point files (the files used to define the movement of group leader) are used for different topology in RPGM.

Secondly, we study a scenario which contains 3 nodes with a simulation time of 1000s in an area of 300m x 300m. Two extreme nodes are fixed at positions (40, 40) and (260, 260), respectively. Because of the too large distance, they can not be directly connected. To construct a route between them, another node is used. The characteristics of node movement are similar to RWP.

The pause time is null and the maximum speed Vmax varies from 1 to 5m/s by step of 0.5m/s, then from 10 to 40 m/s by step of 5m/s to generate different movement patterns for each mobility model. 15 scenarios in each speed of mobility models are created.

For RWP model (10 nodes) and RPGM (5 groups of 2 nodes), the traffic pattern is composed of 6 connections. For RWP with 50 nodes and RPGM with 5 groups of 10 nodes, there are 30 connections. The source/destination pairs are chosen randomly. Data rate is 4 packets/sec and the packet size is 512 bytes. A nominal bit-rate of 2 Mb/sec and a nominal radio range of 250 meters are used.

For the studied scenario, the traffic pattern consists of 1 connection.

D. *Correlation coefficient*

To measure the effectiveness of the mobility metrics, we computed correlation coefficient. Its value between -1 and 1 measures the degree to which two variables are linearly related. For a perfect linear relationship with positive slope between the two variables, we have a correlation coefficient of 1; with negative slope correlation is -1. If there is positive correlation, whenever one variable has a high (low) value, so does the other or variable does the opposite in negative correlation case. A correlative coefficient of 0 means that there is no linear relationship between the variables.

E. *Expected relations between mobility metrics and evaluation parameters*

Because a good mobility metric must be able to indicate or predict the protocol's performance, we first predict the relationship between the mobility metrics and the speed of mobile node as shows in Table 1-a. Then we are going to compare experimental results with the expected results.

We predict relationship between performances and mobility metrics as are in Table 1-b.

Table 1. Relationship of mobility metrics with the maximum speed and the performance metrics

Mobility Metric	Speed	
	Low	High
LC	Low	High
LD	High	Low
LS (= LD/LC)	High	Low

(a) the mobility metrics and the maximum speed

Mobility Metric	PDR		Routing Overhead	
	Low	High	Low	High
Speed	High	Low	Low	High
LC	High	Low	Low	High
LD	Low	High	High	Low
LS	Low	High	High	Low

(b) the performance metrics and mobility metrics

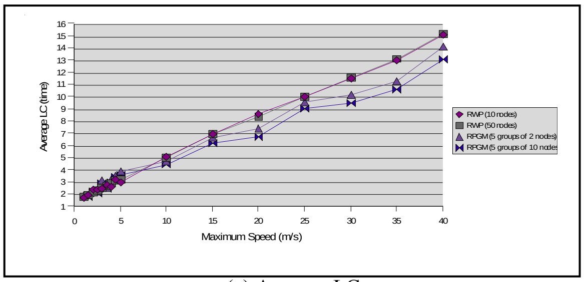
V. SIMULATION RESULTS AND DISCUSSION

A. Mobility metrics and speed relation

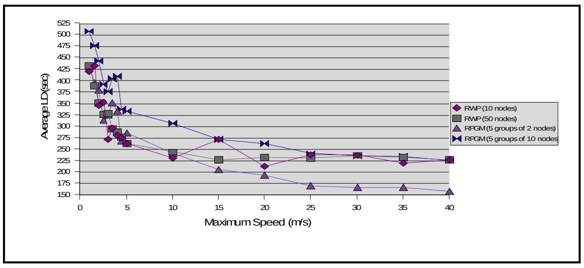
Because our purpose is to test protocols performances in function of metric values, we determine the possibility to obtain growing metric values by increasing the speed value in the simulation. The metric values obtained (Fig 3) are reported on the X axis of figures 4, 5, 6, 7 and 8.

In addition, from this simulation, we note the comportment of metrics.

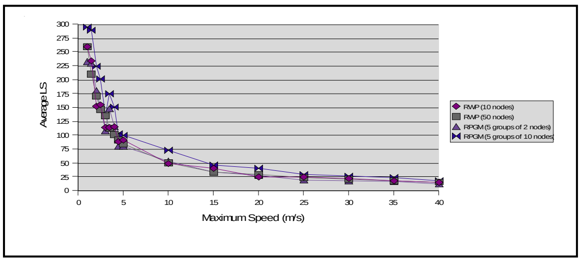
In Fig 3-a, the speed affects forcefully the average LC.



(a) Average LC



(b) Average LD



(c) Average LS

Figure 3. Mobility metrics according to maximum speed

At a very low speed, the average LC is low, while the speed increases, the average LC increases relatively.

In Fig 3-b, the speed affects also the average LD. For very low speed, the average LD is considerable high. As the speed increases, the average LD increases relatively. Beyond a speed of 25 m/s, the average LD changes a little because the mobile nodes move very fast to a destination, choose the new destination and move to it, and so on. At these speeds, nodes can connect with another node in very short period but very frequently as stated from Fig 3-a. Consequently, the average LD is likely to be stable when the speed exceeds 25 m/s.

According to Fig 3-c, the speed also affects the average LS. The average LS results from the average LD divided by the average LC. Then the average LS looks like the average LD. Above a speed of 25 m/s, the average LS slightly changes too.

The comportment of LC would seem the most conform to reflect mobility as it linearly increases with the speed. Nevertheless, results show that *"speed"* is not a good metric of mobility (see next section.). At this step, we can not decide on what the best mobility metric is.

B. Performance and mobility metrics relation

The observed protocol performances are PDR and Routing Overhead. Firstly, we study them according to the speed (Fig 4). Secondly we classify the scenarios according to the average LC (Fig 5) and, LD (Fig 6) and LS (Fig 7) and obtain the corresponding performance.

A first general remark concerns the good aspect of the results. In our study, a result is good if it is conform to the expected results summarized in Table 1-b. As shown in Figs 4 through 7, the performances are not relatively good in RWP 10 nodes and RPGM 5 groups of 2 nodes, in the other hand, the performances are relatively very good in RWP 50 nodes and RPGM 5 groups of 10 nodes. For example, the PDR in RWP 10 nodes and RPGM 5 groups of 2 nodes does not relatively decrease when the speed increases (Fig 4-a), in the same way the PDR does not relatively decrease when the average LC increases (Fig 5-a). Same constitution for the average LD (Fig 6-a) and average LS (Fig 7-a).

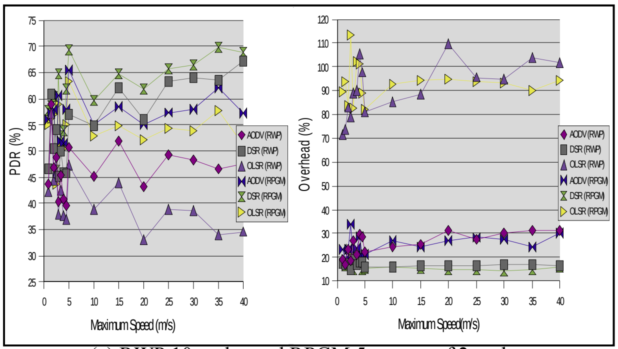
However, for the routing overhead for the RWP 10 nodes and RPGM 5 groups of 2 nodes scenarios, the mobility metrics are relatively better than those of PDR. Nevertheless, the PDR and Overhead in RWP 50 nodes and RPGM 5 groups of 10 nodes with all mobility metrics are relatively good (Fig 4-b, 5-b, 6-b, 7-b).

It appears that the node density influences the interest of mobility metric. An explanation is in the metrics computation process since they are based on average computation when the number of nodes increases the accuracy is more precise.

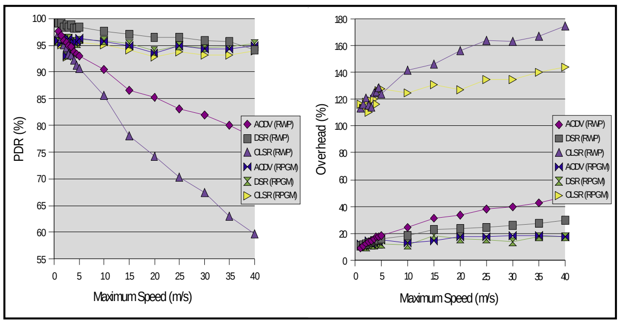
Another remark concerns the influence of the routing protocol combined to the mobility models. Especially, comparing DSR and OLSR on high density, mobility metrics have less influence on the PDR of DSR. Probably, it is due to the cache route mechanism of DSR. But for a network with a high load (higher density and traffic), because cache route may contain a lot of stale routes, PDR and overhead would be more affected.

Moreover, the results show that PDRs in RPGM with 5 groups of 10 nodes slightly change because of the nature of this model. The mobile node sends the packets to any group of nodes directly connected to it.

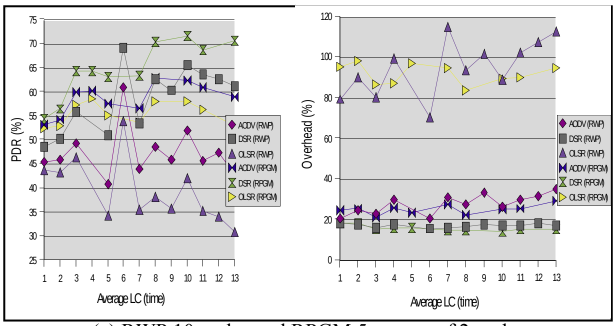
The PDRs in RWP 50 nodes are very variable (e.g. at the fastest speed, most frequency average LC, least average LD and least average LS, the PDRs of all protocols are the lowest). The reason for this is that the network topology is changed with the speed that affects the LC, LD and LS. Then, the nodes got many route



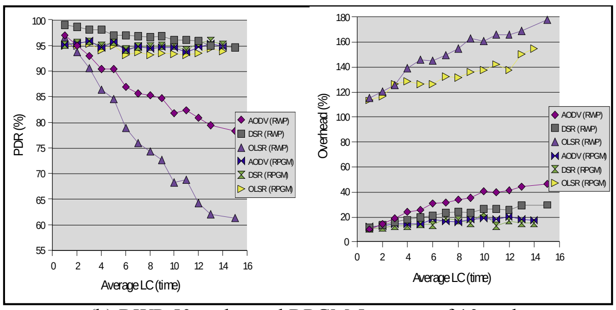
(a) RWP 10 nodes and RPGM 5 groups of 2 nodes



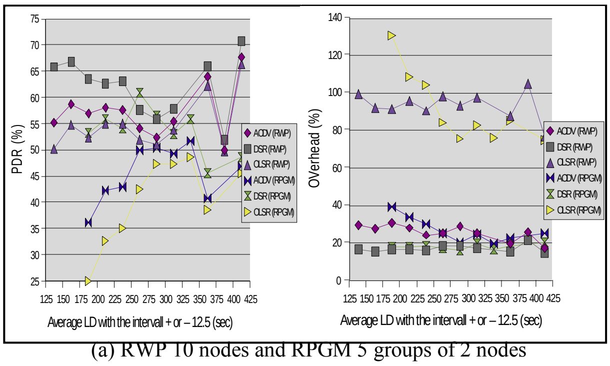
(b) RWP 50 nodes and RPGM 5 groups of 10 nodes
Figure 4. Performances relative with the speed



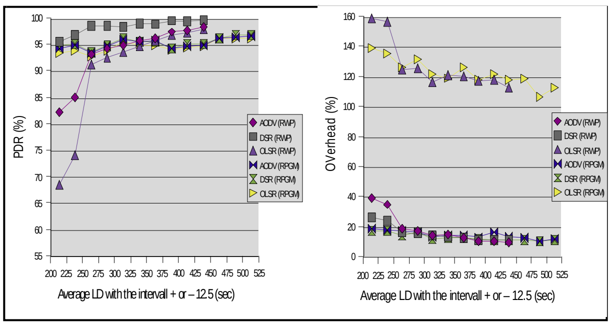
(a) RWP 10 nodes and RPGM 5 groups of 2 nodes



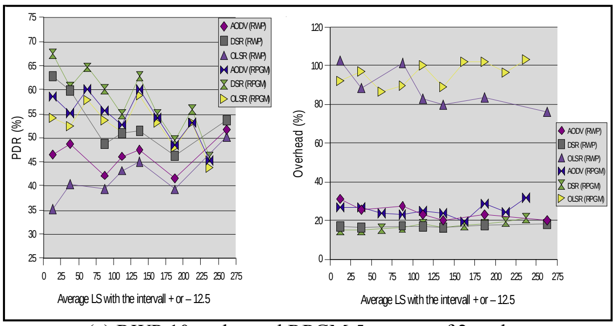
(b) RWP 50 nodes and RPGM 5 groups of 10 nodes
Figure 5. Performances relative with the average LC



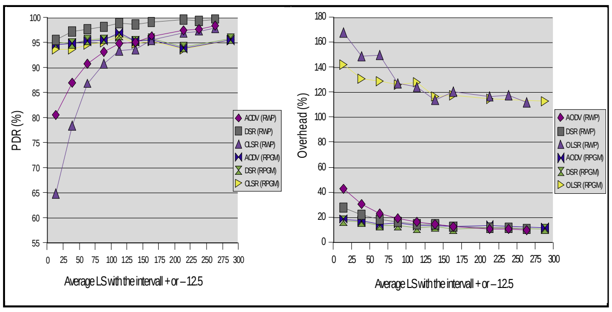
(a) RWP 10 nodes and RPGM 5 groups of 2 nodes



(b) RWP 50 nodes and RPGM 5 groups of 10 nodes
Figure 6. Performances relative with the average LD



(a) RWP 10 nodes and RPGM 5 groups of 2 nodes



(b) RWP 50 nodes and RPGM 5 groups of 10 nodes
Figure 7. Performances relative with the average LS

errors; try to find the new route to the destination and so on. This leads to a very large amount of the overhead in an unstable network.

The mobility metrics are not good for RWP with 10 nodes and RPGM with 5 groups of 2 nodes due to the influence of the node distribution, the node density and the calculation methods. For instance, lets consider two nodes that are connected together during 1000s, the LD and LS is increased, but the two nodes can not connect with another node because of the long distance.

In addition, we have observed a relationship between the mobility metrics and the protocol performance (not reported here) in RWP 50 nodes and RPGM 5 groups of 10 nodes. The correlation coefficient is very high when we use the speed or the average LC in RWP 50 nodes. However, the correlation coefficient is the highest when the average LD is used in RPGM 5 groups of 10 nodes.

In conformance with performance evaluations done on ad hoc routing protocols, in this experiment, the PDR of DSR is the best in all cases. OLSR has the most overhead in all cases because it is the proactive protocol. Furthermore, OLSR has the least performance because of the relatively small size and density of the network simulation (OLSR is benefit to large networks).

Important parameters for the accuracy of mobility metrics are the number of nodes and the stability. It is clearly shown in the results that, whatever the routing protocol and the mobility model, best results are obtained with 50 nodes than with 10 nodes. In a same way, the metric is more representative when the network stability is high. Moreover, the average that is done in the computation leads to some inaccuracy. In case of low number of nodes, the number of neighbors for each node is not sufficient to obtain valuable value; the confidence interval is too large. Note that the confidence interval can be reduced by an increase of the observation period, but in this case the adaptation process would be too long to reflect the network dynamic.

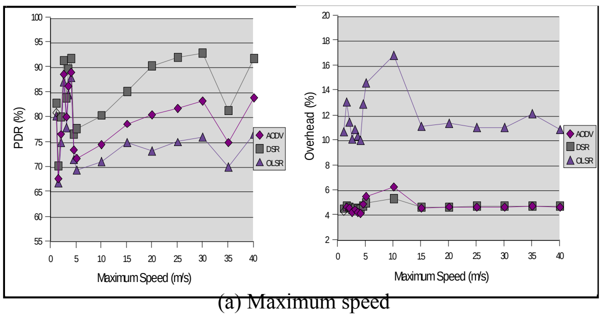
C. Mobility metrics effect on a scenario

The previous sub section B highlights the limitation of the analytical formula for the mobility calculation. Therefore, a scenario approach is tested.

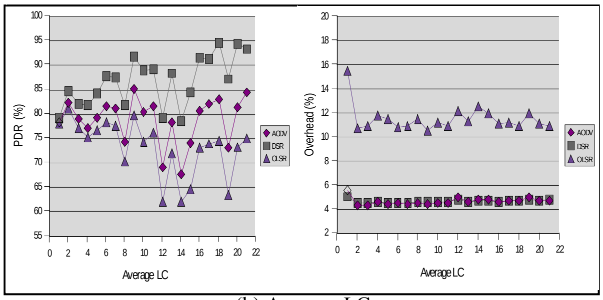
As previously, we focus on the protocol performances. Firstly, they are compared with the speed (Fig 8-a). In addition, all the scenarios of speed are classified in the average LC (Fig 8-b), LD (Fig 8-c) and LS (Fig 8-d) respectively. Then, they are evaluated with the mobility metrics.

As shown in Fig 8-a through 8-d, the performances are relatively good only with the average LD. Ideally, the lowest LC should give the best performance. Practically, the performance depends on LD, not on LC. We explain it by the example presented in Fig 2.

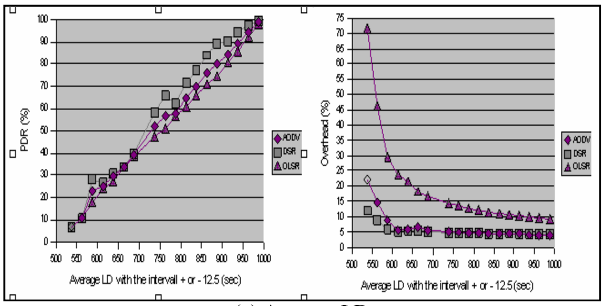
The PDR of DSR is the best in all the cases. OLSR has the most overhead in all cases. OLSR has the least performance because of the size and the density on simulation. The average LD is the best mobility metric when the proposed scenario is observed; correlation coefficient is about 0.99 whatever the routing protocol



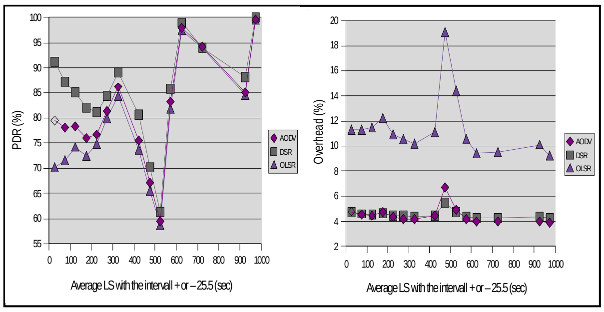
(a) Maximum speed



(b) Average LC



(c) Average LD



(d) Average LS

Figure 8. Performances according to mobility metrics

VI. CONCLUSION

The study indicates that the important parameters for the accuracy of mobility metrics are the node density distribution and the stability. The method of mobility metric calculation affects directly the metric accuracy.

Furthermore, considering an evaluation based on a scenario approach, it appears that the Link Duration metric is the best metric as it impacts in a similar way the routing protocol. Thus, we note that even if there is no universal mobility metric, since study on general model can not decide of a best metric, for a specific case, the best mobility metric can be found. Interest of this result concerns the conception of mobility oriented self adaptive protocols. They have to determine their right metric before to use it. We recommend that, as the concept of quality of service, which is implemented by a set of parameters, the mobility concept will be implemented by a set of metrics.

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