Maximizing Mobile Multimedia Adhoc Networks Lifetime Using a Distributed Cooperation mechanism

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ABSTRACT: *Energy conservation is a critical issue in wireless multihop ad-hoc networks, which have nodes powered by batteries only. One major metric for energy conservation is that all nodes participate in relaying requests which may be opposite to its interest but can be a solution for extending the network lifetime. We proposed a distributed algorithm which gurabtuees a cooperation between the nodes in function of their energy provision. We focus in this paper on the exploitation of nodes mobility. Experiments results show the impact of nodes mobility on the behavior of our proposed algorithm.*

Subject Categories and Descriptors
C.2.1 [Network Architecture and Design]: *Wireless communication;* **C.1.4 [Parallel Architectures]** *Mobile processors*

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Multimedia networks, Ad hoc networks, Energy conservation

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1. Introduction

A mobile ad hoc network (MANET) is an autonomous system consisting of mobile hosts connected by wireless links. It can be flexibly, quickly deployed and dismantled easily for many practical applications such as battlefield operations, festival grounds, search and rescue and disaster relief emergency. Unlike wired networks or cellular networks, there is no physical infrastructure and central administration in mobile ad hoc networks. Every host can move in any direction at any speed and any time. These factors among others introduce a dynamic topology. Namely, nodes have to support, in addition to their own workload, the network functionalities (e.g., routing and relaying). However, wireless nodes are power constrained and consequently have a limited lifetime. They must then make use of this resource as rational as possible. From that, each node, participating in the wireless ad hoc network, has to ”deal” with on one hand the energy spent in performing the network functionalities and on the other hand the one spent for its own use. The objective of each node is to maximize its own lifetime. Reaching such objective stands for reducing tasks execution, especially the relaying tasks. However, if every node does not accept to relay tasks, the connectivity of the network disappears! Nodes are then concerned with both maximizing their own lifetime and guarantying at the same time that the wireless network will continue to work/exist (e.g., maximizing the lifetime of the network).

To illustrate this ”dilemma”, let’s consider the example of figure1. In this example, suppose that nodes are taking pictures from a sporting competition (football for instance) and exchanging them. Note the key position of node C which allows it to make the ”bridge” between nodes. Assume that X is a limited node (PDA or cell phone for instance). Therefore, in order to view the exchanged content, it has to perform adaptation tasks i.e., resizing pictures or adapting videos for instance. In addition to that, it has to relay packets to the rest of nodes due to its position. In this case, its lifetime will decrease rapidly (see case 1 in figure1) leading consequently to a significant reduction in the network lifetime as well. Note that the lifetime of the network is defined as the maximum time period during which a certain data collection function or task can be carried out without any node running out of energy [1]. In this scenario two cases are possible:

1. In the first case, every node executes itself the tasks of multimedia adaptation. This scenario is illustrated in Figure 1, first case.
2. In the second case, a “*deal* ” has been found between nodes, so that node C performs only the relaying tasks and that all the other nodes, which are supposed to have higher energy provisions, share the adaptation tasks. Each node participates in function of its own energy provision, in order to allow node C to view the content of the sporting competition. In this scenario the lifetime of the network is maximized as illustrated in figure 1, case 2.

To find such a ”deal” between nodes, we proposed a decentralised cooperation approach between nodes that guarantees to every node participating in the network that its participation is conditioned on one hand on its remaining energy provision and on the other hand on its actual workload [2]. The key idea behind our approach is that every node runs a cooperation algorithm that communicates only with its immediate neighbours. Tasks exchange is trigged if nodes do not have the same ratio (e.g., remaining task with regard to the remaining energy provision). After a certain number of iterations, we proved analytically that all nodes reach the same ratio, guarantying hence the ”fairness” of our cooperation scheme. The overall improvement of the network lifetime due to our proposed cooperation algorithm was between 17% and 55% depending on the considered network topology.

In this paper, we focus on an important aspect that has not been studied in previous works, namely **nodes mobility**. In fact, in several realistic scenarios such as students in an university campus, we were facing nodes mobility. We were interested to study and measure nodes mobility impact on the performance of our proposed approach. As confirmed previously [2], our ap-

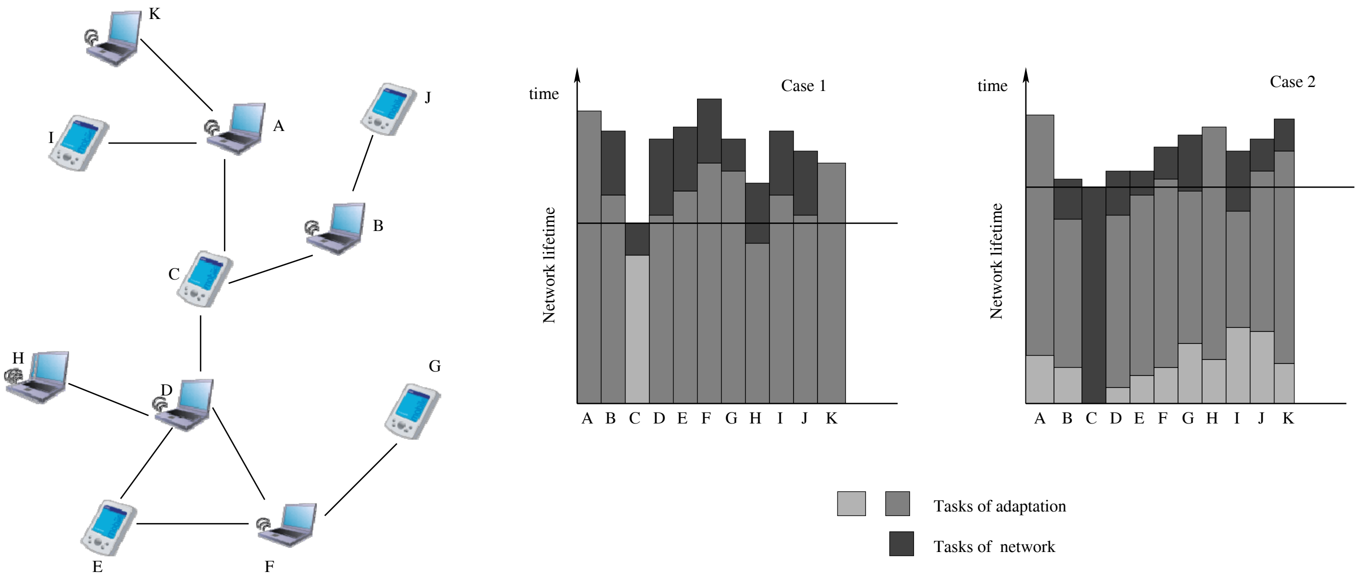

Figure 1. Motivations

proach is topology sensitive and nodes mobility leads to varying topologies. Our objective hence is to study more closely the behaviour of our approach in the context of nodes mobility in particular its robustness and the induced cost.

The rest of the paper is organized as follow: Section 2 presents the related work. Section 3 describes formally the problem. In Section 4, we present our cooperation approach. Section 5 highlights the corresponding experimental results. Section 6 concludes the paper and points out our future work.

2. Related Work

A great amount of recent work studied the problem energy consumption in wireless Adhoc networks; the objective is, of course, the maximization of the lifetime. To address this issue, several power-aware routing protocols

and topology control algorithms have been developed, [3]. In most cases, the goal is to minimize the energy consumed per packet in order to deliver it to the destination. In [5], the authors attempt to study the problem of power consumption using linear programming formulation. They give a heuristic algorithm to solve the linear program approximately, the algorithm can prove to be bad in certain cases. In [6], the authors formulate the problem as a maximum concurrent flow problem. The algorithm finds an approximation to a feasible flow if one exists. A number of other papers have considered the topic of energy-aware broadcasting in wireless networks (e.g., [7], [8]), the problem is to maintain a transmission graph which connects a given source node to all the other nodes. The aim of most of these works is to minimize the total power consumption of the entire network. Research works addressing cooperation in wireless ad hoc network in order to optimize nodes energy could be found in [9, 10, 11]. Nodes in the network use these algorithms to accept or reject relaying packets in the network. In [9] an observation approach tries to detect nodes which agree to relay traffic but do not, and avoid routing through these nodes. In [10] nodes relaying packets for the other nodes are remunerated and nodes receiving packets are charged. This allows the authors to propose an acceptance algorithm. In [11] the objective has been to optimize the lifetime in the context of a dynamic power schedule, i.e. when the powers can be adjusted directly during operation. The authors proved that finding optimal power schedules for multicasting is NP-hard in the dynamic case and thus not likely to be exactly solvable by a polynomial-time algorithm. They assumed that the nodes are immobile.

Our approach is based on cooperation between nodes in order to prolong the whole network lifetime when at the same time ensuring ”fairness” to every node i.e., its participation is mainly conditioned by its energy provision. In this sense, it could be complementary to some approaches mentioned above.

3. The problem

We assume that time is slotted and s means for a duration of one time slot. We then note any instant t in function of s as: $t = k \times s$ where $k \in \mathbb{N}$. For sake of simplicity, we use k instead of t to denote an instant. We used the notation reported in Table 1. We consider a finite population of N nodes each of which is associated with an initial energy provision (at $k = 0$), noted $E_i^{(0)}$. Furthermore, as tasks i are different i.e., the energy needed to execute them differs from a set to another (e.g., application tasks, etc.), we consider M different subsets of tasks. Each subset contains a number of identical tasks.

Symbol	Signification
Ω :	the finite set of heterogeneous nodes (Ω= $\{n1,n2,...,nN\}$)
N :	the number of considered nodes in the wireless ad hoc network (N =$\lvert\Omega\rvert$)
n_i :	the identifier of a node ($n_i \in \Omega$).
$E_i^{(k)}$:	the energy provision of node ni at instant
$E_i^{(0)}$:	the initial energy provision of node n_i
$T_{i,j}^{(k)}$:	the number of tasks of class j, that node n_i holds at instant k.
$T_{i,j}^{(0)}$:	the initial number of tasks of class j, that node n_i holds.
$e_{i,j}$:	the energy needed to node n_i to execute one task from class j.
$N_{i,j}^{(k)}$:	the number of tasks of class jexecuted by node n_i during time slot k.

Table 1. Notations used in the paper.

Recall that our objective here is to optimize $E_i^{(k)}$. we are i then looking for a time slot S such that equation 1 holds .

$$\forall k > S, = \frac{\Sigma_{j=1}^{M} T_{1,j}^{(k)} e_{1,j}}{E_1^{(k)}} = \cdots = \frac{\Sigma_{j=1}^{M} T_{N,j}^{(k)} e_{N,j}}{E_N^{(k)}} \quad (1)$$

Where $T_{i,j}^{(k)}$ stands for the remaining tasks of class j that node n_i holds at instant k (i.e., the remaining workload):

Equation 1 states that the ratio between the needed energy to execute the remaining workload and the available energy is nearly the same for **all nodes**. Hence, we ensure that all nodes participate in function of their available energy, and consequently that our approach is fair with regard to all nodes.

4 . Cooperation Algorithm

The goal of our approach is to make nodes cooperate in a way that equation 1 holds and remains valid. This cooperation is based on tasks exchange between nodes such that all nodes hold the same ratio. Here we precise that all tasks are not "exportable" i.e., exchangeable between nodes. For instance, relaying tasks could not be transferred between nodes. This is not the case of other tasks as multimedia adaptation tasks that are by nature exchangeable provided that all nodes hold some standard adaptation tools. We tacked into account this important aspect in our analysis.

Our proposition is founded over an algorithm, executed periodically by every node, responsible of the exchange of tasks between nodes neighbours when needed. Our previous theoretical work [2] proved that all nodes converge towards a state satisfying Equation 1. This remains valid even in the case of momentarily break of the communications or in the case of dynamic change of the network topology .

Let us use the following notation,

$$x_i^{(k)} = \frac{\Sigma_{j=1}^{M} T_{i,j}^{(k)} e_{i,j}}{E_i^{(k)}} \quad (2)$$

Let $V_i^{(k)}$ denotes the set of nodes neighboring node n_i at instant k. We note here that our approach takes into account the fact that neighbors are changing i.e., the network topology is changing over time. Here after, each node performs the following algorithm:

Algorithm 1: ratio computing

if $V_i^{(k)} \neq \varnothing$ **do**
  Exchange $x_i^{(k)}$ with each $n_\upsilon \in V_i^{(k)}$
  i.e., send $x_i^{(k)}$ to n_υ and receive its $x_\upsilon^{(k)}$
  Compute $x_\upsilon^{(k=1)} - x_i^{(k)} + \Sigma_{n\upsilon \in V_i^k} A_{i\upsilon}^{(k)} (x_v^{(k)} - x_i^{(k)})$
  if $x_i^{(k+1)} - x_i^{(k)} > \in //$ convergence condition
    Exchange tasks with nodes in $V_i^{(k)}$
    according to algorithm 2
  endif
endif

Remark 1: $V_i^{(k)} = \varnothing$ models the situation where node *i* is not reachable at time *k*, due for example to congestion flow problems.

The principle of our algorithm is to compute, at each iteration, the next ratio $x_i^{(k+1)}$ and deduce the amount of tasks to exchange with neighbors. The new ratio is calculated from the old ratio and the differences between the node ratio and ratios of its neighbors. This difference is weighted by factor $A_{iv}^{(k)}$.

When the convergence criteria is not reached i.e., each node has to send/receive tasks from its neighbourhood, it first computes the amount of tasks to exchange with its neighbours and then selects which tasks from which class have to migrate. To find the number of tasks as well as their nature, we proceed as follow:

Assume node n_υ is neighbouring node n_i at instant k $n_\upsilon \in V_i^{(k)}$, suppose that ni has to send tasks to n_υ i.e. $x_\upsilon^{(k)} - x_i^{(k)} < 0$, Furthermore, let's $a_{i,j}^{(k)}$ stands for the number of tasks of class j that node n_i has to send to node n_υ at instant k. Recall that our objective is to find $a_{i,j}^{(k)}$.

From Algorithm 1, we have:

$$x_\upsilon^{(k+1)} = x_\upsilon^{(k)} + \sum_{n_n \in V_\upsilon^{(k)}} A_{\upsilon n}^{(k)} (x_n^{(k)} - x_\upsilon^{(k)}) \quad (3)$$

On the other hand, as node nv will exchange tasks with its neighbors, we can note:

$$x_\upsilon^{(k+1)} = x_\upsilon^{(k)} + \sum_{n_n \in V_\upsilon^{(k)}} \frac{\Sigma_{j=1}^{M} \alpha_{n,j}^{(k)} e_{n,j}}{E_n^k} \quad (4)$$

From equations 3 and 4 and the fact that node n_i is a neighbor of node $n_\upsilon \in V_i^{(k)}$, we deduce that

$$A_{\upsilon i}^{(k)} (x_i^{(k)} - x_\upsilon^{(k)}) = \frac{\Sigma_{j=1}^{M} \alpha_{i,j}^{(k)} e_{i,j}}{E_i^{(k)}} \quad (5)$$

Hence,

$$\sum_{j=1}^{M} \alpha_{i,j}^{(k)} e_{i,j} = A_{\upsilon i}^{(k)} \left(\sum_{j=1}^{M} T_{i,j}^{(k)} e_{i,j} - E_i^{(k)} x_\upsilon^{(k)} \right) \quad (6)$$

Note that equation 6 admits several solutions. This gives us the opportunity to *tun out* the algorithm to exchanges tasks from various classes.

In case we deal with one class of exchanged tasks, we obtain,

$$\alpha_i^{(k)} = A_{\upsilon i}^{(k)} \left(T_i^{(k)} - \frac{E_i^{(k)} x_\upsilon^{(k)}}{e_i} \right) \quad (7)$$

Algorithm 2: exchanging tasks

for each node $n_\upsilon \in V_i^k$ **do**
  if $\left(x_\upsilon^k - x_i^k < 0\right)$ **do**
    compute $\Sigma_{j=1}^{M} \alpha_{i,j}^k e_{i,j} = \Sigma_{j=1}^{M} T_{i,j}^k e_{i,j} - E_i^k x_\upsilon^k$
    Send $A_{i\upsilon}^k \times \alpha_{i,1}^k$ tasks of class 1,
      $A_{i\upsilon}^k \times \alpha_{i,2}^k$ tasks of class 2,
      . . .,
      $A_{i\upsilon}^k \times \alpha_{i,M}^k$ tasks of class M.
  endif
endfor

The weighting factors, as presented in the algorithm, allow to each node to balance the exchanged tasks between its neighbours. For the sake of an easy implementation and an accelerated convergence, we have used in our implementation a symmetric and doubly stochastic matrix. In our experiments we constructed the matrix $A^{(k)}$ as follow:

Algorithm 3: construction of diffusion matrix A_i^k at iteration k

for (i from 1 to N) **do**
  for (j from 1 to N and j≠i) **do**
    if $\left(\upsilon_j \in V_i^{(k)}\right)$ **do**

$$A_{ij}^{(k)} = \frac{1}{Max[(d(i),d(j)]+1}$$

    else

$$A_{ij}^{(k)} = 0$$

    endif
  endfor

$$A_{ij}^{(k)} = 1 - \Sigma_{j=1,\, j \neq i}^{N} A_{ij}^{(k)}$$

endfor

Where $d(i)$ means for the degree of node n_i i.e., the number of neighbors of node n_i.

5. Experimental results

In order to evaluate the effectiveness of the proposed algorithm in different situations, mainly in mobile environments, we have implemented a discrete-event simulation package using OMNET++ [12] framework including nodes mobility extension. Furthermore, in order to be as close to reality as possible, we have used realistic models of energy consumption of multimedia tasks.

5.1 Models of energy consumption

In [13, 14], the authors measured the energy consumption of an IEEE 802.11 network interface controller. From those measurements, energy consumption is modeled through linear equations. These equations model data transmission and reception considering different type of communication, i.e., broadcast, unicast or packet discarding. We used the equations obtained for the *Lucent WaveLAN IEEE 802.11 Silver* card.

Margi et al.[15] have studied the energy consumption induced by various tasks execution on a wireless laptop (DELL Latitude C600), in particular in image transformation (FFT: Fast Fourier Transform) context. They considered four types of tasks: *baseline* (system tasks), *processing-intensive (FFT)*, *storage-intensive* and *communication-intensive*. We used their results in our framework to characterize the energy consumption of nodes. They also provide a similar analysis for the Crossbow Stargate platform that performs video acquisition. Again, we used their results to characterize another class of nodes.

5.2 Simulation settings

Several parameters are distinguished and fall into four categories:

- *Type of nodes:* we considered two types of nodes with the according settings. The first type (termed A) represents nodes with limited battery power and computing capabilities (PDA for instance). The second type (termed B) represents nodes with higher energy power and computing capabilities. The initialization of these two types of nodes followed the results of Margi and al[15], which we have referred to previously. We used three classes of tasks: tasks of multimedia capture, tasks of adaptation-intensive (FFT), and tasks of communication-intensive, each of which with its corresponding energy consumption factor. The number of nodes was generated randomly between 5 and 40 nodes. We though that this number corresponds to a realistic configuration of a wireless AdHoc network (friends or students in a campus). In the rest of our simulation we although vary the proportion of nodes A with regard to nodes B in order to measure the impact of network heterogeneity on the performance of our approach.
- *Initial network topology:* As mentioned before, our approach is sensitive to the network topology. In our experiments, we set the initial topology from which nodes start to move and consequently create varying topologies. We considered three classes of initial topologies: (a) Random Topology (RT) that was generated randomly, (b) Linear Topology (LT) in which every node has at most two neighbours and (c) Fully Connected Topology (FCT) where every node communicates directly with the all nodes.
- *Nodes mobility:* Nodes movement was generated randomly. In other terms, each node has a fixed speed (1 m/s) and a random direction. Node's direction changes every 1 minute[1]. However, to maintain the network connectivity, we have introduced the following mechanism: at each time a node disconnection risk is detected (i.e., its communication radius becomes smaller than its distance to the nearest node), we stopped its movement and proceeded to a direction change such that this risk is avoided.

5.3 Simulation Results

- In order to study the impact of nodes mobility on our proposed approach, we firstly measured the overall gain in term of network lifetime improvement in the context of nodes mobility and compared it to the static case (when nodes do not move). We also studied the impact of some parameters like the number of nodes in the network as well as their nature. We recall that a network is considered as "dead" when at least one node is out of energy. Following that, we measured the network lifetime improvement as follow: for every set of settings, we run the simulation twice: with and without using our algorithm. Then, we compute the difference in term of ratio improvement.

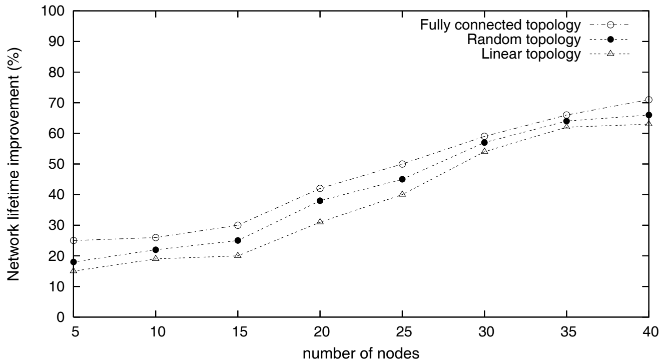

Figure 2. impact of nodes number on the lifetime of the network (fixed topologies)

- Figures 2 and 3 present the network lifetime improvement due to our approach in both fixed topologies and mobile context. We noticed that the improvement is always impacted by the network topologies. In fact, the convergence is rapidly

[1]We have varied this parameter and we have not noticed any impact on the overall performance.

reached in some topologies (e.g., fully connected for instance) as all nodes are neighbours. Thus, the improvement is better than in ”slow” convergence topologies. As shown in the figures, FCT present better results than LT. RT present middle results between FCT and LT that are considered as the two extreme topologies. This difference remains true in both contexts (fixed and mobile). As expected, the improvement is better in fixed topologies than in mobile ones. This is because in mobile context, the simulation starts from initial topologies and then after, the network topology evolves randomly and continuously to a mixture between the three topologies. Consequently, our algorithm needs more iterations to reach the convergence criteria. The improvement is then decreased.

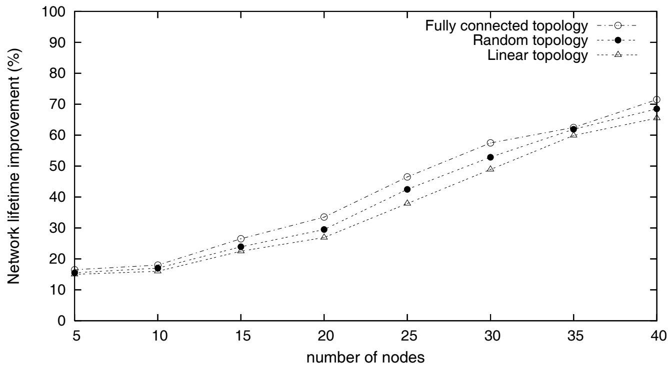

Figure 3. impact of nodes number on the lifetime of the network (mobile topologies)

We also noticed that the improvement increases with the number of nodes in the network what ever the topology is. The reason is that high number of nodes gives a rise of an important difference in energy provision between nodes. Consequently our approach behaves better since it tries to balance tasks between nodes with regard to nodes energy provisions. In some sense, it saves low energy provision nodes to ”dead” prematurely.

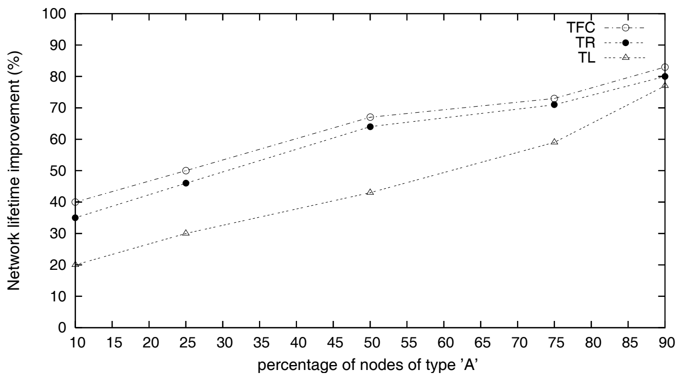

Figure 4. impact of number of nodes of type (A) on the lifetime of the network (fixed topologies)

We also studied the impact of network heterogeneity on the performance of our approach. In other terms, we varied the proportion of nodes of type A (nodes representing PDA, cell phones, etc.) in the network. Again, we studied fixed topologies as well as mobile ones. The results are plotted in Figures 4 and 5. As expected, the improvement increases with the increase of the proportion of type A nodes. For the same reason invoked before, higher the difference in nodes energy provision, better

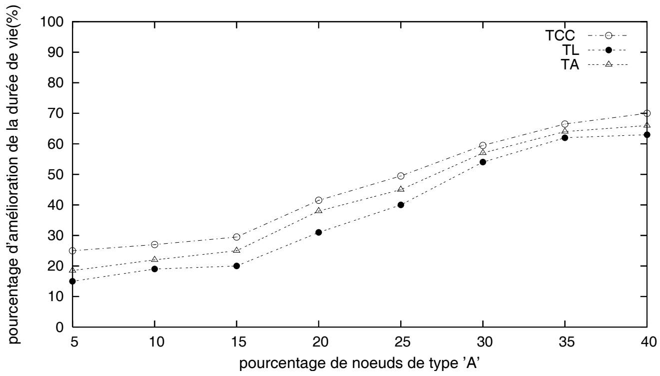

Figure 5. impact of number of nodes of type (A) on the lifetime of the network (mobile topologies)

the improvement is. It has to be noted that fixed topologies showed better results than mobile ones although the improvement remains significant in both context.

Finally, figure 6 presentes the impact of the augmentation of speed of nodes mobility on the network lifetime for a Random topology with 25 nodes. We noticed that the percentage of improvement of network lifetime decreases when the nodes move more quickly. It is because of the additional energy spent because of the rapide change of topology and consequently the rediscovery of neighbours.

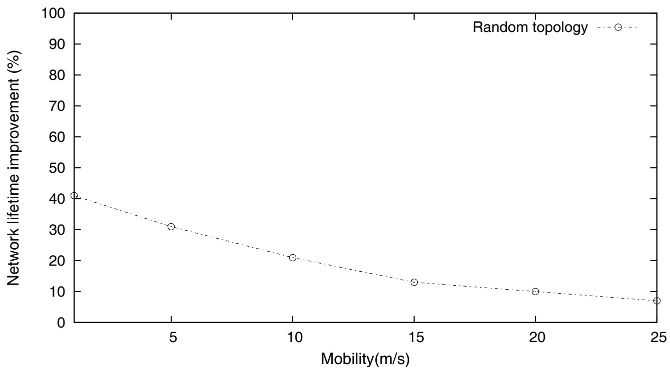

Figure 6. Impact of speed of nodes mobility on the network lifetime

6. Conclusion and future work

In this paper, we presented a decentralized approach that attends to prolong the network lifetime. This approach is well suitable for noisy AdHoc environments since nodes communicate only with their neighbours; it is by nature very robust against communication niosy. Furthermore, we experienced its effectiveness in mobile environments where network topology is continuously changing. Though the improvement is better in static context than in mobile one, our approach improves notably the whole network lifetime. In future work, we will tackle the problem of link heterogeneity. In fact, we considered that all nodes use the same network interface and hence have the same link capacity. In practice, there exists several network interfaces with several capacities. We want to extend our work to cope with this issue by changing the weighting factor matrix. However, the main difficulty resides in the fact that it is very hard to continuously monitor a communication link, especially in mobile AdHoc environments. We have to face the potential benefits to the introduced costs.

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