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Abstract: The present note proposes a survey of protocol overheads in mobile ad-hoc networks. An analysis is proposed to estimate overhead due to control packets. An analysis and simulations are proposed to estimate overhead due to non-optimality of the routes constructed by some protocols.

Key-words: wireless network, ad-hoc, overhead, flooding, hello

(Résumé : tsvp)

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Overhead dans les protocoles de réseaux sans fil ad-hoc

Résumé : Plusieurs protocoles de routages sont proposés pour les réseaux sans fil ad-hoc (sans infrastructure). Pour les comparer, nous proposons une analyse de la surcharge de trafic apportée par les protocoles eux-mêmes. Une synthèse sur les différents protocoles existants est proposée. L'analyse se découpe en deux parties : analyse de la surcharge due aux paquets de contrôle et analyse de la surcharge due à la non-optimalité des routes dans certains protocoles.

Mots-clé : réseau sans fil, overhead, inondation, hello

1 Introduction

The objective of this note is to survey the overheads met by mobile ad-hoc network protocols in particular between reactive protocols and pro-active protocols.

Topology of radio networks is usually dense and varies often. We are going to see that control overhead in protocols for this type of networks depends mainly on the way routes are constructed. Manet protocols [16, 4] propose mainly two ways for creating routes in ad-hoc networks:

1. the classical one consists in every node emitting hellos in order to learn the topology (a mechanism is then used to broadcast this information or a sufficient part of it to be able to compute routes);

2. on the other hand, a very simple way of finding a route consists in flooding, the source floods a packet and the path followed by the packet to reach the destination is used.

These two approaches are very different with regard to control overhead. In that sense the analysis made in this paper segregates the protocols proposed for ad-hoc networks in two main flavors: "hello protocols" and "flooding protocols".

The second approach is very attractive for two reasons: information is stored only for active routes (the rest of the topology may be ignored) and it allows to create quickly a route in reaction to large mobility. Almost all the proposed protocols at Manet use this mechanism. The most popular is AODV [22, 21] by Charles Perkins. Such a protocol will be called a "flooding protocol".

The first approach may take advantage of the long routing experience in fixed networks (for example, OSPF reacts better to link and node failure than RIP) but seems to produce more overhead, and coming from fixed networks, one could think that it reacts badly to network mobility. We are going to see that it is not always the case. There is mainly one protocol of this flavor proposed at Manet: OLSR [17, 11] by Qayyum, Jacquet, and Muhlethaler is inspired from the routing part [12, 13] of the link layer protocol Hiperlan [3]. It is a link state protocol in the style of OSPF that makes specific optimizations for radio networks. This proposition takes advantage of the knowledge of the topology locally to make efficient broadcasting. Such protocols will be called "hello protocols".

	Flooding protocols	Hello protocols
Fixed overhead	$3\lambda N^2$	$(hd + \tau r\delta)N^2$
Mobility overhead	$3\min(\mu L, h)aN^2$	$\min(\mu\delta, h)\delta r N^2$

Table 1: Bandwidth overhead of both protocol flavors. Table 3 details the parameters used.

Table 1 presents our first main result concerning control overhead. The other main result of the present note concerns the overhead due to non-optimality of routes obtained by flooding. Table 2 gives a foretaste of the analysis and simulations presented later.

	Optimal distance 2	Optimal distance 3	Optimal distance 4
Line with continuous density	2.2	3.4	4.3
Plane with continuous density	2.7	4.5	6.2
Strip with 50 nodes	2.1	3.2	4.3
Square with 79 nodes	2.3	3.6	4.9
Grid with 49 nodes	2.2	3.4	4.5

Table 2: Average length of routes obtained by flooding for nodes at distance 2, 3 and 4 in various scenarios.

Other flooding protocols proposed at Manet include TORA [20, 5] by M. S. Corson and V. Park, DSR [15, 14] by J.Broch, D.Johnson and D.Maltz, ODMRP [18, 19] by S.-J. Lee, M. Gerla, and C.-C. Chiang, and RDMAR [1, 2]. Some of these protocols are specifically designed for QoS or multicast support. Some of these optimize their flooding cost. These various optimizations are not analyzed in the present note. Nevertheless, we believe that the main cost terms identified in this paper are still valid for these protocols up to some multiplication factors to be identified in each case.

Another pro-active protocol proposed at Manet is STAR [7, 8] by J.J. Garcia-Luna-Aceves and M. Spohn. The use of a "neighbor protocol" and link state update packets (LSU) may suggest that it is a hello protocol (in the sense that neighbors are discovered pro-actively). However, the authors seem to deny the use of hello packets. The way neighbors are discovered and routes are constructed in this protocol is still unclear to us. Finally, there is an hybrid proposition: ZRP [9] by Z.J. Haas and M.R. Pearlman that cumulates both hello packets and floodings.

We are going to see that both approaches may overtake the other depending on the profiles of the network and the traffic. A generic model is given in Section 2 taking in account density of the network, mobility, traffic creation, and traffic density. Sections 3 and 4 are devoted to the estimation of control overhead by analyzing both the number of control packets and their bandwidth cost. Section 5 deals with the overhead due to the non-optimality (in number of hops) of routes. Section 6 compares both flavors for some scenarios.

2 Model for radio networks

We need some parameters to model the network in a simple manner that allows to compare both protocol flavors in a tractable way. They are summarized by Table 3. We suppose that the shape of the network is roughly stable (the parameters bellow are supposed constant) and that it is always connected. In the sequel, N denotes the number of nodes in the network,

Network parameters	
N	number of nodes
M	number of edges
$\Delta = 2M/N$	average degree of a node
$d = \Delta/N$	link density
μ	link breakage rate (mobility)
L	average length of a route

Traffic parameters	
λ	route creation rate per node
a	number of active routes per node (activity)

Protocol parameters	
h	hello rate
τ	topology broadcast rate
δ	average size of topology broadcast packets
R	average number of retransmissions per broadcast
$r = R/N$	broadcast optimization factor

Table 3: Parameters used to analyze protocols overhead.

M the number of edges (we consider that two nodes are linked by an edge if they are able to communicate directly, each one is then neighbor of the other), Δ the average degree of a node (the degree is the number of neighbors of a node). The density of the network will be important in the following analysis, we will thus use the *link density* $d = 2M/N^2 = \Delta/N$. To model mobility, we introduce μ, the average number of link breakage per link during a second (a link lasts $1/\mu$ seconds in average). We assume that it is constant and that link creation balances link breakage (M is supposed constant), *i.e.* $M\mu$ links, in total, are created per second. Notice that it is logical to suppose that the total number of link creation or link breakage is proportional to the number of links. Another parameter depending mainly on the shape of the network is the average length L (number of hops) of a route.

Concerning control overhead, we mainly need to model traffic creation. Let λ denote the average number of route creation by a node during a second. Another influent parameter is the number of simultaneous active routes per node, denoted by a. This model is rather simple but it is sufficient to compare the two routing approaches.

Some parameters depend on the protocols. Hello protocols include regular hellos, and regular broadcasting of topology information. Let h and τ be the number of hellos and broadcast information packets respectively emitted by a node during a second. (All parameters are expressed in terms of rates to be consistent.) As hello protocols discover the topology through the hellos, a hello packet mainly includes the list of neighbors of a node. Its size is thus approximately Δ addresses. Let δ denote the average size of the topology packets broadcasted by a node. Hello protocols can use their knowledge of the topology to optimize broadcasting. Ideally, N/Δ emissions are sufficient to broadcast an information to every node. This has to be compared to N emissions for a flooding. Let R be the average number of emissions to achieve a broadcast, we denote by r the broadcast optimization factor, *i.e.* $r = R/N$ $(1/d \leq r \leq 1)$.

Flooding protocols may include hellos for detecting link breakage. h will then also denote their rate. Otherwise the link layer is used to detect link breakage. In that case, an interesting parameter is the minimal time between two consecutive floodings for a fixed destination from the same source. It is bounded by the time that the reply from the destination needs to reach the source. Typically, it is in the same order of magnitude as the hello period (around 1 second). We will thus use $1/h$ for this time.

We are now able to analyze protocol overheads of both flavors.

3 Control overhead in fixed network

We consider in this section the control overhead in a fixed network. The additional cost of mobility is considered in the next section. The main control overhead of flooding protocols is due to the floodings. One flooding costs the emission of N packets of constant size. On the other hand, the main control overhead of hello protocols is the periodic emission of hellos which have a size proportional to Δ. Let h be the number of hellos per second. They cost hN packets per second. The cost can also be estimated in terms of bandwidth: a hello packet size is Δ times the address length; hellos thus use a bandwidth of $h\Delta N = hdN^2$ (the implicit unity is the address size per second). Now, let us go in more details.

3.1 Route creation overhead

To create a route in flooding protocols, the source makes a flooding and the destination sends a reply by the route followed by the first packet of the flooding it receives. This costs $\lambda N \times (N + L)$ packets of constant size per second. A flooding packet mainly contains the addresses of the source and destination of the route, and the address of the emitter of the packet. The bandwidth cost is thus approximately $3\lambda N(N + L)$. Hello protocols have the advantage of having all routes ready for use and do not make any overhead at route creation. On the other hand, their fixed control overhead includes the cost of route creation.

3.2 Fixed control overhead

In a hello protocol, each node emits every $1/h$ second a hello containing the list of nodes from which it hears hellos and its own address ($\Delta + 1$ addresses). This allows to ignore unidirectional links; moreover, each node learns the local topology up to 2 hops (a node knows its neighbors and the neighbors of each one). This local information is used to optimize broadcasting. For example multi-point relay sets are computed in OLSR. These sets allow to efficiently broadcast (see [10] for some analysis). Hellos thus cost hN packets per second and a bandwidth of $h(\Delta + 1)N$.

To compute routes, a minimal subset of the topology has to be broadcasted. In OLSR, the knowledge of all the multi-point relay sets is sufficient to compute shortest path routes (see [17, 12, 13] for more details). This broadcasting costs rN emission per broadcast, that is $\tau r N^2$ packets per second, and a bandwidth of $\tau r \delta N^2$.

With an adapted OSPF, one would expect $\delta = \Delta + 1$. But in a dense network, a carefully selected subset of size $O(N)$ of the $O(N^2)$ topology should be sufficient. An optimized hello protocol should have a small δ. On the other hand, the knowledge of the full topology locally allows to avoid useless retransmissions during broadcasting. Ideally, each retransmission would inform Δ new nodes. In practice, with an optimized hello protocol, only a percentage of them will be newly informed, yielding $r = O(N/\Delta)$. (See [17, 10, 12, 13] for details about such optimizations.) See Section 6 for some estimations of r and δ.

The fixed overhead of hello protocols is thus $(h + \tau)N$ packets per second, using a bandwidth of $(hd + \tau r \delta)N^2$.

If a flooding protocol uses hellos to detect link breakage, its hello overhead will be hN packets per second, using a bandwidth of hN. We will neglect this linear factor in the sequel (and keep only quadratic terms). Conversely to what one would think at first glance, flooding protocols do involve a fixed control overhead even without hellos and route creation: as there is an active route timeout (for mobility management reasons), a route may expire if it is not used frequently enough. We integrate this overhead in the previous factor by supposing that λ is the rate of route creation or refreshing after timeout.

4 Control overhead due to mobility

In both cases, mobility is visible through link breakage and creation. A link breakage is detected either when some hellos are no more received or when a link failure is reported by the link layer.

4.1 Link breakage

When a link breakage occurs in a route, the routing information must be quickly updated. In flooding protocols, a packet is sent to the source which proceeds to route creation. This thus corresponds to a $\mu \times L \times aN$ rate of flooding due to link breakage (a link breakage is harmless when no route uses the link). considering that link breakage detection is bounded by h and that the rate at which a node makes floodings for a fixed destination is bounded by h, as discussed in Section 2, this rate is always bounded by h. The overhead due to link breakage is thus $\min(\mu a L, ha)N \times (N + L)$ packets of three addresses per second.

The only case where an hello protocol will make additional control due to link breakage is when a link of the broadcasted topology breaks. An additional broadcast packet updating this information is then broadcasted. The probability that a link breakage occurs in the broadcasted topology is δ/Δ. A node will thus send an additional broadcast packet with rate $\mu\delta$. However this rate is bounded by the link breakage detection rate (*i.e.* h). The additional overhead due to link breakage in hello protocols is thus $\min(\mu\delta, h)N \times rN = \min(\mu\delta, h)rN^2$ packets per second with a bandwidth of $\min(\mu\delta, h)(\delta + 1)rN^2$.

	Flooding protocols	
	Packets	Bandwidth
Fixed overhead	λN^2	$3\lambda N^2$
Mobility overhead	$\min(\mu L, h)aN^2$	$3\min(\mu L, h)aN^2$

	Hello protocols	
	Packets	Bandwidth
Fixed overhead	$\tau r N^2$	$(hd + \tau r\delta)N^2$
Mobility overhead	$\min(\mu\delta, h)rN^2$	$\min(\mu\delta, h)\delta rN^2$

Table 4: Main contribution terms to control overhead in ad-hoc network protocols. Costs are given in number of packets per second in bandwidth.

4.2 Link creation

A link creation is not noticed in flooding protocols until a new route using the link is created. No additional overhead thus occurs. As above, the only additional overhead for hello protocols may come from a broadcast topology updating. But in the case of a link creation, there is no need to send an additional update packet before the periodic one. No additional overhead occurs in both protocols.

Table 4 summarizes the analysis of both protocol flavors control overhead. They both include an $O(N^2)$ overhead. We now focus on an other type of overhead: traffic increase because of non-optimal routes.

5 Non-optimal routes overhead

Hello protocols have the advantage of computing optimal routes [17]. Constructing routes by flooding is very simple but may lead to non-optimal routes quite often. The analysis of the length of the routes obtained by flooding is quite tricky. We will restrict ourselves to a one dimensional analysis and simulations in two dimensional space. Considering a flooding, we call flooding distance of a node the length of the constructed route from the flooding source to the node. We call distance of a node the length of an optimal route from the source to the node. We are going to try to estimate the ratio flooding distance over distance.

5.1 One dimensional analysis

Suppose the nodes are densely placed on a line. We consider the propagation of a flooding on the positive side of the axis made by the line. The origin of the axis is the flooding source as origin and its unit is the range of a node (an emission at position x covers $[x-1, x+1]$). At a fixed time the nodes willing to re-emit the packet form a dense set in an interval $[0, x]$. Any node in that set may succeed in emitting (this is due to randomization in the channel

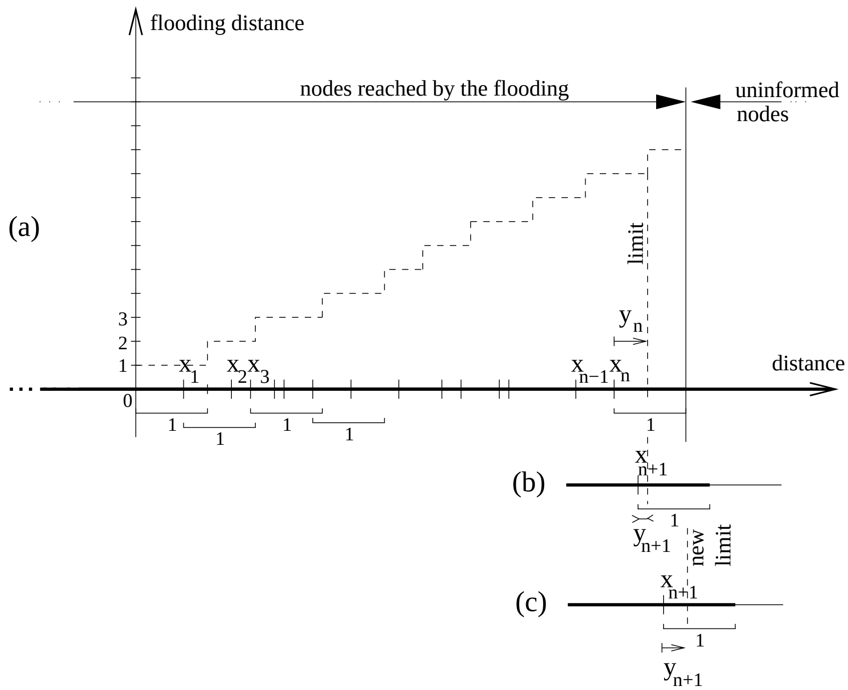


Figure 1: (a) Flooding distance versus distance after the emission of x_n. Discontinuities in this function are called limits. A limit is always at position $x_i + 1$ for some x_i. (b) Case where the next emission on the right of x_n is on the left of the limit $x_n + y_n$. (c) Case where the next emission on the right of x_n is on the right of the limit $x_n + y_n$.

access protocol). To follow on the extension of this interval, we only focus on the emissions that occur in the interval $]x-1, x]$ (the others do not change anything to the propagation process and the flooding distance). Let $x_0 = 0$, x_1 be the position of the first emission in $]0,1]$,..., x_{n+1} be the position of the first emission in $]x_n, x_n + 1]$.

In $]x_n, x_n + 1]$, let $x_n + y_n$ be the limit between the nodes that have same flooding distance as x_n and those having flooding distance one more than x_n. (The flooding distance is clearly an increasing function, and as the nodes in $]x_n, x_n + 1]$ have received the emission of x_n, their flooding distance is not greater than the flooding distance of x_n plus one.) See Figure 1 for an illustration.

Indeed we can compute the probability distribution of y_n. Let $f_n(y)\mathrm{d}y$ be the probability that $y_n = y$. Notice that y_{n+1} depends only on y_n. As illustrated by Figure 1, there are mainly two cases depending on the position of x_{n+1} with regard to the limit $x_n + y_n$. If it is on the left, one gets $x_{n+1} + y_{n+1} = x_n + y_n$, the limit for $]x_{n+1}, x_{n+1} + 1]$ is the same as for

$]x_n, x_n+1]$. If it is on the right, one gets $x_{n+1}+y_{n+1} = x_n+1$, the limit for $]x_{n+1}, x_{n+1}+1]$ is the right bound of $]x_n, x_n+1]$. We immediately deduce the following recurrence (remember that x_{n+1} is uniform in $]x_n, x_n+1]$):

$$f_{n+1}(y) = \int_y^1 f_n(z) \times \mathrm{d}z \ + \ \int_0^{1-y} f_n(z) \times \mathrm{d}z$$

Clearly $f_1(y) = 1$. We thus deduce $f_2(y) = 1 - y \ + \ 1 - y = 2(1-y)$. We then compute $f_3(y) = 2 - 2y - 1 + y^2 \ + \ 2(1-y) - (1-y)^2 = 2(1-y)$. f_n is thus stationary for $n \geq 2$ with $f_n(y) = 2(1-y)$.

The mean value of y_n is thus $\int_0^1 2(1-y)y\mathrm{d}y = 1 - 2/3 = 1/3$. The probability that a new flooding distance limit is created is thus $2/3$. The average distance of x_n is clearly $n/2$. Its flooding distance is the number of distinct flooding limits in $[0, x_n]$, *i.e.* $2/3 \times n$. The ratio flooding distance over distance in this model is thus $4/3$ approximately. That means that non-optimal routes will cost an overhead bandwidth of 33 % of the optimal traffic bandwidth.

5.2 Simulations

We first present simulations close to the previous model. It is possible to simulate a flooding with a continuous density of nodes: the next emitter is chosen at random in the area covered by the flooding. After 1000 emissions, 1000 nodes are chosen at random in the area covered by the flooding at that time and their flooding distance and distance are computed. Figure 2 shows the evolution of the ratio flooding distance over distance for 1D simulations and 2D simulations. We can see that the simulations confirm our 1D analysis and show that the ratio flooding distance over distance tends towards 1.6 approximately in 2D. Notice that the 2D curve is abnormally decreasing for large distances. This is an artifact of the simulation: a finite flooding is made (1000 emissions) so that an edge effect is observed for large distances. This phenomenon will be encountered on all simulations.

To have a more realistic idea of the non-optimality of flooding routes, we have made simulations with a discrete model: we suppose that nodes are placed randomly in a LxH rectangle and that the range of a node is 100 meters in all directions (it covers a disk of radius 100). Figure 3 illustrates the simulation of one flooding in this model. Figures 4 and 5 present simulation results (of thousands of floodings) with a strip (a 1000x50 rectangle) and a square (500x500) with different densities of nodes. The distance of a node is now the length of a shortest route from the source. Notice that the values observed for large distances are less meaningful since few nodes reach these values. We can see that high density simulations get close to the continuous case results. However, for very sparse distributions, the ratio can get as low as 1.05. This is still a very important factor in terms of overhead since it represents 5 percents in addition to the traffic bandwidth (*i.e.* around .5 Mb/s in a charged 11 Mb/s network).

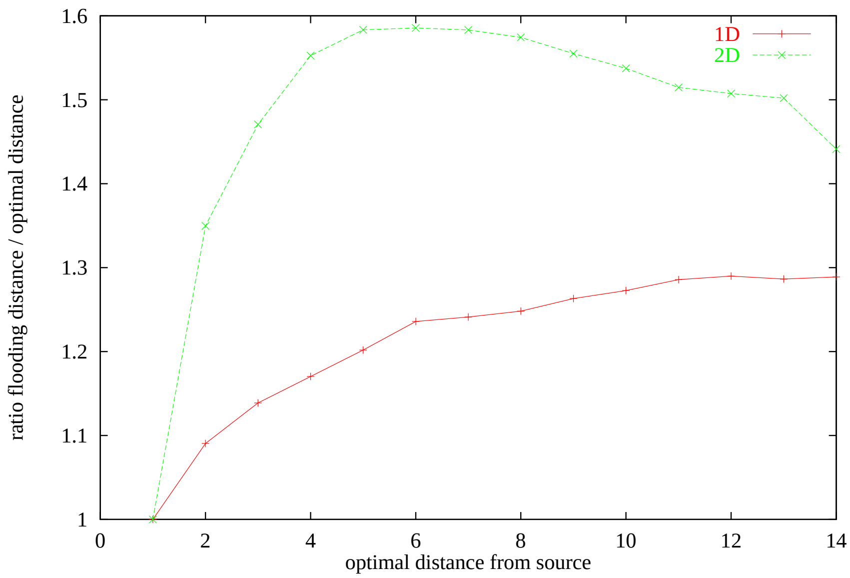


Figure 2: Ratio flooding distance over distance versus distance for a continuous density of nodes on a line (1D) or on a plane (2D).

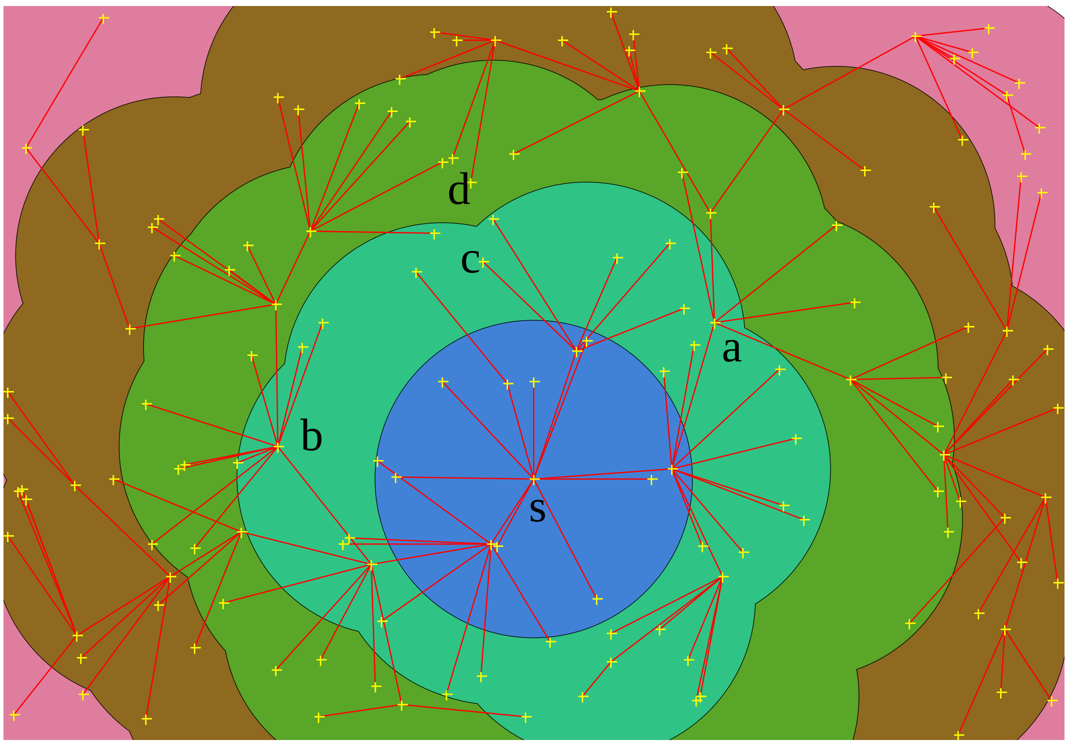


Figure 3: A flooding from s. The disk around a node is the area covered by that node. The crosses figure the nodes and the lines show the routes constructed by the flooding. The background illustrates the shortest distance from s: nodes in an area with same color are at the same distance from s (furthest nodes are at distance 5). For example, node d is at flooding distance 6 from s and at distance 3 from s. This is simply due to a quicker propagation of the flooding from a and b than around c in this flooding (remember that all nodes are in competition for access to the media).

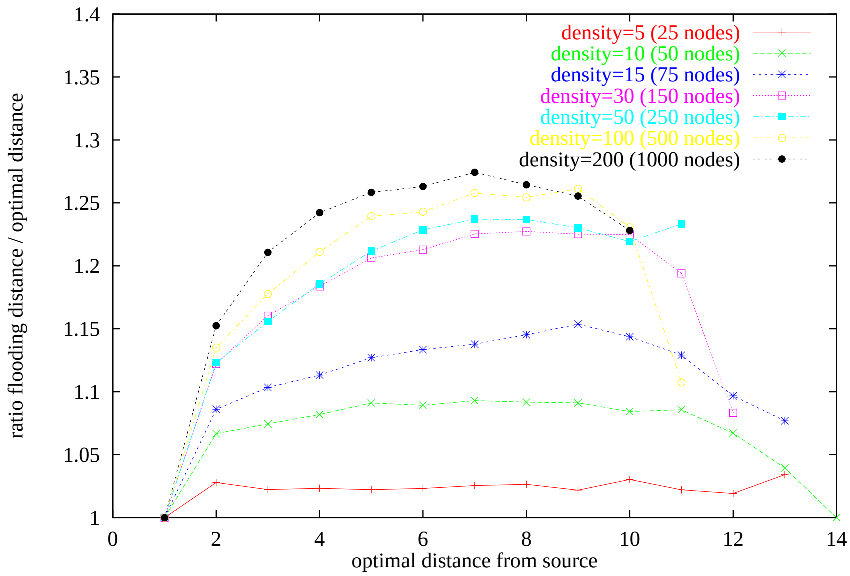


Figure 4: Ratio flooding distance over distance versus distance in a 1000x50 strip for different densities. The density is given in number of nodes per unit area where a unit area is the area covered by a node (2x100x50).

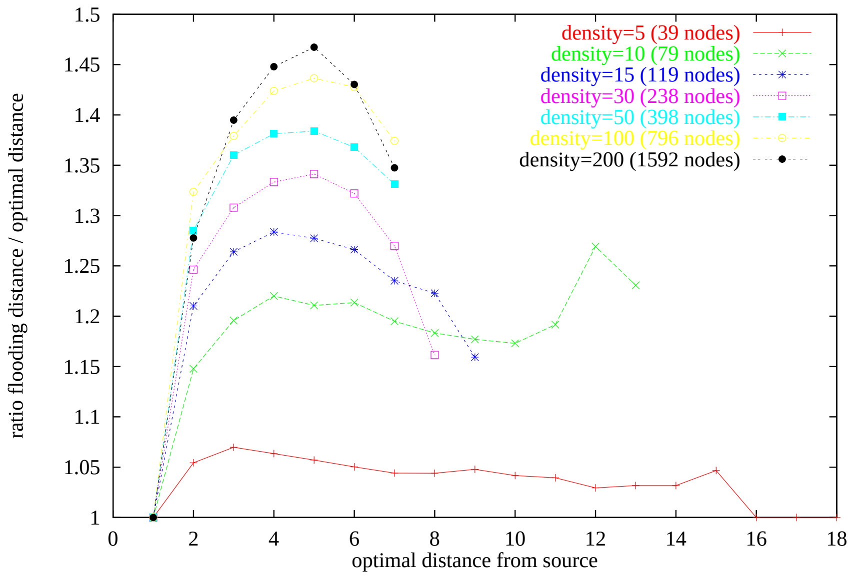


Figure 5: Ratio flooding distance over distance versus distance in a 500x500 square for the same densities as Figure 4. The density is given in number of nodes per unit area where a unit area is the area covered by a node (3.14x100x100).

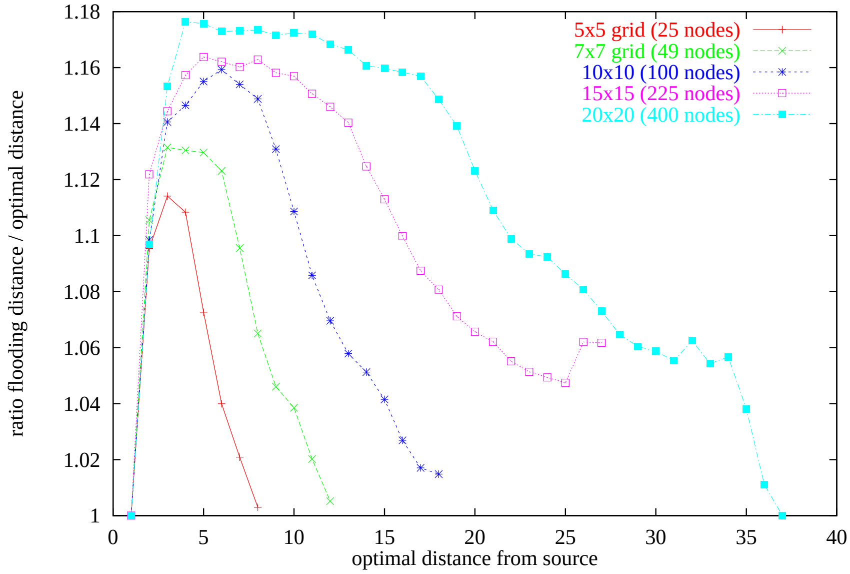


Figure 6: Ratio flooding distance over distance versus distance with a square grid topology.

In order to grab the minimum overhead cost of non-optimality of flooding routes, we have made simulations on the square grid: each node has 4 neighbors (except on the edges). It is connected enough to be a reasonable network topology and it is very sparse. Moreover, it is a reasonable model for Manhattan. Notice that in the analogous 1D model (a line where each node has two neighbors), there is a unique route to each node and the flooding obviously gives optimal routes. Figure 6 shows the results obtained for various sizes of square grid. We observe the worst ratio for the middle distance nodes (far nodes certainly benefit from the edges of the grid that force the flooding to reach them straightly). Even for a rather small grid, one can get a 1.1 ratio for distance 3 nodes.

Now that we have an idea of non-optimal routes overhead, we consider some scenarios for comparing control overhead.

6 Control overhead comparison in some scenarios

To give a point of comparison with non-optimal routes overhead, we give the control overhead of flooding protocols for $N = 100$, $\lambda = 0$, $a = 40/100$, $\mu = 1/25$ and $L = 4$. This values correspond to those used in the simulations presented in Figure 7 of [6]: 40 sources of traffic are used over 100 nodes yielding $a = 40/100$, constant bit rate give $\lambda = 0$, a range of 250 meters and a speed of 10 meters per second correspond to $\mu = 1/25$, and the 2200x600 geometry of the field roughly gives $L = 4$. With IPv4 addresses, the formula given in Table 4 estimates the control overhead to 61 Kbits/sec. Notice that this estimation perfectly agree with the simulations of [6] for low offered loads (for higher loads the simulations of [6] show a control overhead that increases slightly).

On the other hand, for a comparable geometry (1000x50 field with range 100) and density (75 nodes), Figure 4 shows that an overhead of non-optimal routes of 10 % the traffic should be expected. This corresponds to 10 Kbits/sec to 80 Kbits/sec for offered loads from 100 Kbits/sec to 800 Kbits/sec. For such loads, both overheads are comparable. But with higher bandwidth networks, non-optimal routes overhead could become preponderant.

6.1 Tolerance to mobility

When the length of a route is L, some link on the route breaks at rate $L\mu$. To be able to route packets between two constructions of the route, flooding protocols require that this rate does not exceed h. The maximal allowable mobility is thus $\mu_F = h/L$ for flooding protocols. On the other hand, hello protocol can repair the route locally, their maximal allowable mobility μ_H is simply bounded by the duration of routes of length 2, giving $\mu_H = h/2$. Notice that report of link breakage by the link layer could allow flooding protocols to increase their flooding rate. To our knowledge, this is not supported by existing technologies, and it is not yet standardized. To compare both flavors, we will thus consider $0 \leq \mu \leq h/L$. Be aware that it $\mu = h/L$ still represents a very high mobility since for $h = 1$ (usual value proposed in protocols [21, 11]) and $L = 10$, this gives $\mu = 1/10$, meaning that the average duration of a link is then 10 seconds...

6.2 Values of some parameters

As overhead becomes critical when the number of nodes is important, we will mainly consider scenarios with a large number of nodes (typically $N = 100$). However some lower values are also considered. To compare both protocols, we need to determine some parameters. First of all, the protocol parameters are known: $h = 1$ for AODV [21] and OLSR [11], $\tau = 0.25$ for OLSR. Concerning the network parameters, we are going to explore different scenarios where we can determine L, d, δ, r in function of N. We will compare the two protocol flavors in terms of μ and a for some values of N. There is still one parameter to determine that models traffic creation: λ. We can link it to the number of active routes per node thanks to the average route duration time T (including the route timeout time). A route is created every $1/\lambda$ seconds, hence $a = T/(1/\lambda) = \lambda T$. Considering web traffic, we will use $T = 10$ seconds, yielding $\lambda = a/10$. We will consider $0 \leq a \leq 1$. For other uses of the network, one might have to consider greater values of a.

6.3 Comparison equation

To compare control overheads, we consider their main terms in bandwidth utilization (those quadratic in N). We need to compare $3(\lambda + \min(\mu L, h))aN^2 = 3a/10 + 3\min(\mu L, h)aN^2$ to

$hdN^2 + (\tau + \min(\mu\delta, h))\delta rN^2$, that is:

$$3\left(\frac{a}{10} + \min(\mu L, h)a\right) \lesseqgtr hd + (\tau + \min(\mu\delta, h))\,\delta r$$

Notice that when mobility is high (μ close to h), the size of the broadcasted and flooded packets becomes critical. The main overhead term is then haN^2 for flooding protocols and $h\delta rN^2$ for hello protocols. This is why minimizing the size of the broadcasted topology is so important in hello protocols. On the other hand, keeping a very small size for flooding packets is very important in flooding protocols. Some protocols of Manet as DSR propose to include the route in the flooding packet. This would lead to a $haLN^2/2$ overhead term compared to $3haN^2$ for AODV. (An average of $L/2$ addresses is included in the packet.) This could be dramatic for a sparse network where it would lead to a cubic term.

6.4 The big room

An example of very dense network is obtained when all nodes are in a big room. Almost any node can communicate with every other. A nice network model for this situation is the random graph where any pair of nodes can communicate with probability p ($p < 1$ close to 1). All pairs are supposed independent.

Route length: A route has length 1 with probability p, and less than 2 with probability almost 1: two nodes are at distance at least 3 with probability $(1-p) \times (1-p^2)^{N-2}$. L is almost $p + 2(1-p) = 2 - p$ (since the length of a route length is bounded by N, $p + 2(1-p) \le L < p + 2(1-p) + N(1-p)(1-p^2)^{N-2}$, with $p = .9$ and $N = 20$, one gets $1.1 \le L < 1.1 + 10^{-12}$).

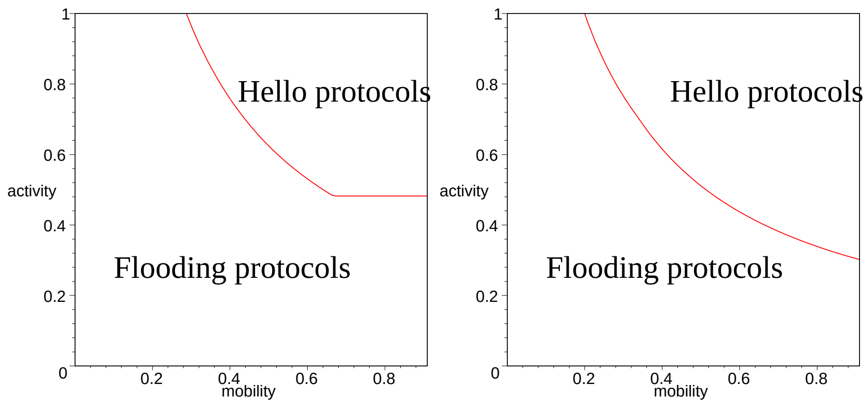
Link density: The average degree of a node is obviously pN. Thus the average link density is $d = p$.

Optimized broadcast: It is shown for OLSR [10] that $\delta \approx 1 + \log_{\frac{1}{1-p}} N$ and $r \approx 1 + frac\log_{\frac{1}{1-p}} NpN$.

Figure 7 presents the regions favorable to each protocol flavor in the plane $\mu x a$ for $N = 100$ with $p = .5$ and $p = .9$. Flooding protocols behave better with higher mobility and low activity.

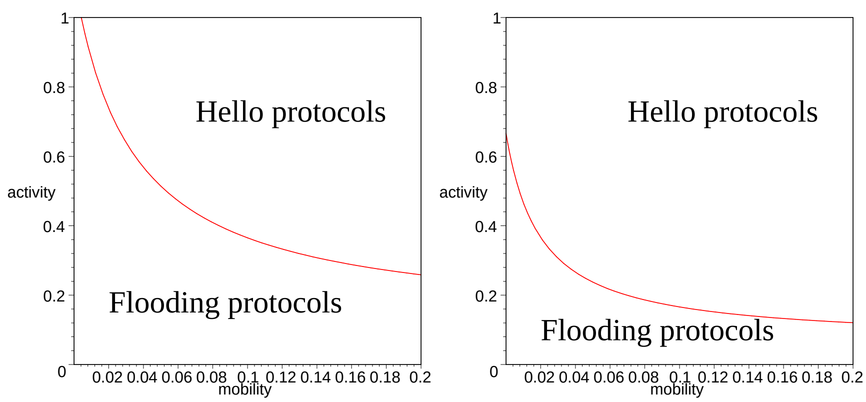
6.5 The dense strip

Consider a large number of nodes placed in a thin strip of length $2L \times R$ where R is the maximal range of a node (the average optimal route length is thus L). The link density is $d = 2R/2LR = 1/L$. Two neighbors per node are sufficient in the broadcasted topology, hence $\delta = 2 + 1 = 3$. (In terms of OLSR, each node has two multipoint relays.) $2L + 1$ emissions are sufficient for a broadcast, hence $r = 2L/N$. Figure 8 presents the regions favorable to each protocol flavor for $N = 60$ with $L = 3$ and $N = 100$ with $L = 5$ (this corresponds to the same density of nodes).



(a) $N = 100,\ p = .5$ (b) $N = 100,\ p = .9$

Figure 7: Comparison of hello protocols and flooding protocols control overheads in the big room scenario. The abscissae is μ and the ordinate is a.

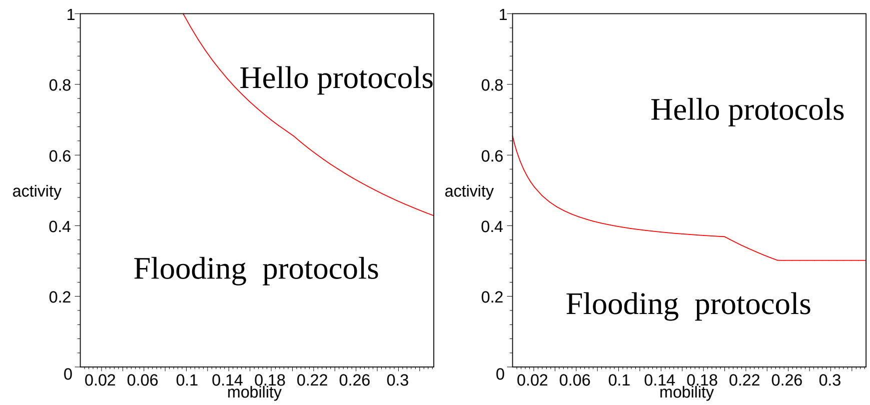


(a) $N = 60,\ L = 3$ (b) $N = 100,\ L = 5$

Figure 8: The dense strip scenario.

6.6 The dense square

Consider a large number of nodes placed in a square of edge length $L \times R$ where R is the maximal range of a node (the average optimal route length is thus $L/\sqrt{2}$). The link density is



(a) $N = 100$, $L = 2$ (b) $N = 100$, $L = 4$

Figure 9: The dense square scenario.

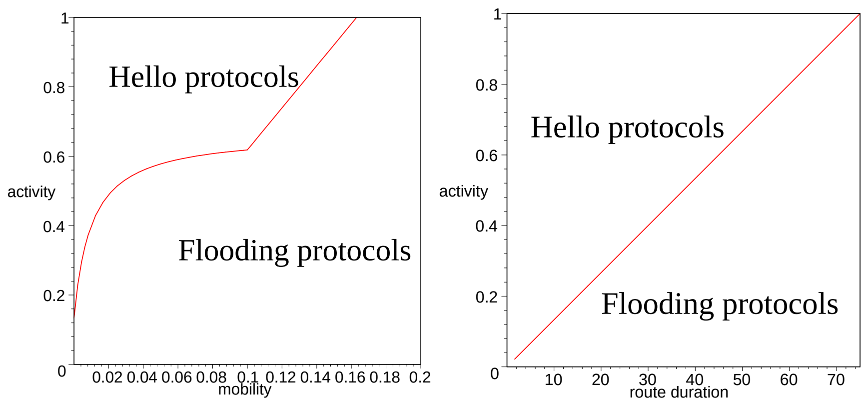
$d = \pi R^2/(RL)^2 = \pi/L^2$. Four neighbors per node are sufficient in the broadcasted topology, hence $\delta = 4+1 = 5$. L^2+1 emissions are sufficient for a broadcast, hence $r = L^2/N$. Figure 9 presents the regions favorable to each protocol flavor for $N = 100$ with $L = 2$ and $L = 4$. Notice that hello protocols seem to behave better with long routes.

6.7 The sparse grid

Suppose the nodes are placed at the intersections of Manhattan. One can suppose that the topology is a grid where every node has 4 neighbors ($\Delta = 4$, $\delta = 5$ $d = 4/N$, $r = 1$). The average optimal route length L is approximately $\sqrt{N}$. Notice that when a link breakage occurs in this scenario, hello protocols will send a broadcast packet with one address less than usual ones since a neighbor has just been lost. However, mobility is not very meaningful in this scenario, and Figure 10 thus presents the regions favorable to each protocol flavor in the Txa plane for $\mu = 0$. Even so a μxa diagram is given for $N = 100$ to be consistent.

Concerning control overhead both flavors of protocols seem to be comparable. Hello protocols have a lower overhead with dense situations, a high number of nodes and with longer routes. Flooding protocols have a lower overhead with high mobility and a low active route number. Concerning mobility recall that hello protocols can support a higher link breakage rate (h compared to h/L) but with a greater overhead cost. Some diagrams confirm that hello protocols behave better with long routes.

As this note tries to survey all Manet protocol overheads, we should discuss the problem of unidirectional links.



(a) $N = 100$ (b) Txa diagram, $N = 100$, $\mu = 0$

Figure 10: The sparse grid scenario. (a) The μxa diagram for $N = 100$. (b) The Txa diagram for $N = 100$ and $\mu = 0$. (The abscissae is the average route duration T here.)

7 Unidirectional links overhead

Unidirectional links should not be used in unicast transmission of packets in general as radio LAN interfaces use acknowledgements for increasing the reliability of the link. This is required when using TCP over the link since TCP can not distinguish packet loss from congestion. Unidirectional links may appear in limit of range or when power control is made.

Hello protocols naturally detect unidirectional links by reading the hellos of their neighbors: if the received hello of a neighbor does not contain the address of the node, it discards the link detecting that the neighbor does not receive its own hellos.

On the other hand, flooding protocols may construct routes that use unidirectional links since floodings are made with link broadcast transmission for which there is no acknowledgement. When the destination sends the reply to the source, the packet is lost on the unidirectional link, and the source has to initiate another flooding. This produces an overhead proportional to the percentage of unidirectional links. This could be damaging if power control is envisioned. However, this percentage is neglectable when all nodes transmit at the same power. But this problem should be addressed in any case as it can lead to systematic route construction failure in some cases of network geometry as illustrated by Figure 11. A great overhead is allowable for cases that are rare, but malfunction even in rare cases should be avoided.

To solve this problem one can identify two possibilities. The same hello mechanism as hello protocols can be used but increasing greatly the control overhead. In that case the

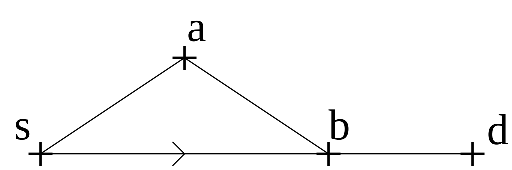


Figure 11: A situation where a unidirectional link prevents floodings by s from constructing a route to d. All links are bidirectional except sb which is unidirectional from s to b. Any flooding will lead to the route sbd because the only valid route $sabd$ will be discarded by b which will refer to the first flooding packet it received.

protocol would cumulate almost both overheads. However, it could also use the optimized broadcast technique instead of the costly floodings. On the other hand, when the link layer reports transmission failures, there is another possibility: when a node fails to send a packet to a possible neighbor, it puts this node in a black list and discards packets from nodes in this black list. When the route is repaired by another flooding, this unidirectional link will be avoided.

8 Conclusion

Control overhead of both protocol flavors has been analyzed. Each protocol flavor can overtake the other in terms of overhead depending on the profile of the topology and the traffic. To summarize, we could say that flooding protocols behave better with high mobility when the number of active routes is low and that hello protocols are more suited when the number of active routes gets high. Another important conclusion is that the size of the broadcasted or flooded packets is critical with regard to mobility control overhead.

The overhead due to unidirectional links can be neglected as long as no power control is made but protocols have to be reliable with regard to unidirectional links. Non-optimality of flooding routes can become problematic for flooding protocols when the topology leads to long routes. This can bring an overhead greater than 10 % of the data traffic even with sparse topologies.

The results presented in this note tend to refine the usual segregation reactive/pro-active protocols by distinguishing those that construct routes with floodings (reactive protocols since this technique allows to construct routes on demand) and those that use the knowledge of the topology which is discovered pro-actively thanks to neighborhood hellos (pro-active protocols).

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