Gateway Discovery Algorithm for Ad-Hoc Networks Using HELLO Messages

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***Abstract*- The connection of ad-hoc networks to the Internet is typically established via gateways. To start an Internet connection, in a first step gateways have to be discovered by the mobile nodes within the ad-hoc cluster. Several algorithms to perform the gateway discovery have been studied in the literature up to now. This paper describes an approach for gateway discovery based on HELLO packets of the AODV protocol. The performance of the new algorithm in terms of the discovery time and the handover delay is compared to the well known methods using NS-2 simulations. Conclusions are drawn from the simulations to further improve the performance of common gateway discovery algorithms.**

Keywords*- multihop ad-hoc networks, MANET, gateway discovery, AODV, HELLO packets

1. INTRODUCTION

Multihop wireless access networks are a key technology in future IP based mobile systems. Because of the limited transmission range of wireless nodes a variety of routing algorithms were developed to give mobile nodes (MN) in mobile ad-hoc networks (MANETs) connectivity, and to enable MNs to connect to the Internet. Therefore, these routing algorithms must have a functionality to interact with gateways that act as an interface between a mobile ad-hoc network and the wired Internet. Ad-hoc On demand Distance Vector (AODV) [1] is a commonly used ad-hoc routing protocol.

If a mobile network has no access to link layer information it may use HELLO messages for neighbourhood management. An interconnection between network layer and link layer protocols provides more efficiency in detecting link losses to neighbour nodes as suggested in [9]. If the actual link layer protocol does not provide information about connectivity to neighbour nodes, AODV uses periodical HELLO messages to indicate the presence of a MN to its neighbours. These HELLO messages can also be used to spread information about an existing Internet gateway throughout the whole mobile ad-hoc network without any protocol overhead caused by advertisements or solicitations. The approach to gateway discovery given in this paper depends on improved HELLO packets and thus, needs no interaction with the link layer.

There are some ideas that can be drawn from the simulations with HELLO discovery algorithm to improve common approaches and therefore, to enhance networks with link layer interaction.

The paper is organised as follows. The next section gives a short overview of the related work while section 3 explains the gateway discovery algorithm with modified HELLO packets based on the AODV protocol in more details. In section 4 we present results of the simulations, where we investigate discovery time and handover performance. Finally, section 5 gives a short conclusion and emphasises possible future work.

2. RELATED WORK

Several approaches to enhance ad-hoc routing protocols to support a MN accessing the Internet were developed. First, there is the so called proactive approach, where the Internet gateway periodically broadcasts advertisements into the MANET to indicate its presence. Secondly, in the reactive approach a mobile node of the MANET asks reactively for gateway services by broadcasting solicitations.

Gateway discovery methods for ad-hoc networks which are based on the proactive and reactive algorithm have been discussed and investigated in [2] [3] and [6]. In [3] several parameters like the number of gateways within a MANET and the mobility of the MNs were investigated. In our paper the emphasis is on interval times of gateway advertisements and mobile node solicitations.

A hybrid discovery algorithm [4] is a combination of the proactive and the reactive algorithm. In this case the gateway sends advertisements, which are only forwarded for a limited number of hops. A MN which does not receive an advertisement for a specified time period, will additionally search for a gateway with the aid of solicitation messages. In [6] the three discovery algorithms are investigated with the aid of simulations. However, handover aspects are not included in the results.

An alternative approach for gateway discovery using HELLO packets is described in [7]. In this paper a testbed is presented with a very small number of nodes within the cluster. Additional, there is only one gateway implemented and therefore, no investigations were performed on handovers.

3. GATEWAY DISCOVERY BASED ON HELLO PACKETS

The newly developed gateway discovery method works with slightly modified AODV HELLO packets (For details on AODV see [1]). HELLO packets have a TTL (Time to Live) of 1 and therefore, will not be forwarded to other nodes. Since they are derived from route reply packets they have a number of unused fields.

In a first step, a gateway sends modified HELLO packets and sets a flag (named I-flag, according to [2]) to indicate that these packets were originated by a gateway and contain the gateway's address. We call this kind of packets HELLO_I packets. Because of the I-flag, each node in the range of the gateway detects the gateway and thus, can set a gateway and default route with a next hop entry pointing to the gateway address for the corresponding nodes in the Internet. In the next step, the neighbour nodes of the gateway set the I-flag and insert the gateway's address into unused fields of their next scheduled HELLO message. A consequence is that the information about the gateway's address is spread all over the MANET and is permanently refreshed with every HELLO packet originated by the gateway. If a MN receives no HELLO_I packet within its HELLO interval, it sends an ordinary HELLO packet instead of a HELLO_I packet. We note that if a gateway is switched on, it takes a relatively long time until every node within the MANET receives the gateway address, since remote nodes may need to wait several HELLO intervals until they hear their first HELLO_I packet. However, this delay is of minor importance because it occurs only when gateways are switched on. In contrast to the proactive and the reactive gateway discovery mechanisms, this concept adds no signalling overhead.

If a MN performs a handover from one MANET cluster to another cluster, it may receive HELLO_I packets from more than one gateway. Then the MN has to decide which gateway would be the best to use. In our implementation a MN uses the nearest gateway, which is defined by the hop count to the gateway. Since HELLO packets have a TTL of one, we utilize a former unused field in the HELLO packet to indicate the distance to the gateway. The gateway itself sends its HELLO packets with a hop count of zero. Any MN sending a HELLO_I packet will increase the hop count by one compared to the received hop count. Consequently, a MN accepts gateway information from another gateway only if the hop count of the new gateway is at least two hops less than the current gateway information. This is necessary, because if a MN which has just performed a handover will spread invalid information of the old gateway into the new cluster. By using only information from a new gateway with a hop count less than two of the current gateway, this spreading of invalid information is reduced.

In the next section the three gateway discovery algorithms, namely proactive, reactive and HELLO_I based, are compared with the aid of NS-2 simulations.

4. NS-2 SIMULATIONS AND RESULTS

4.1 Simulation Scenario and Parameters

To investigate the performance of the three gateway discovery algorithms, the scenario given in Fig. 1 has been set up. In an area of 400 meters times 1000 meters a number of mobile nodes (small circles) are positioned randomly. The mobile nodes do not move, i.e. they remain static. All static mobiles do not create data traffic and are thus, merely used to establish connections for a test mobile node (MN) within the ad-hoc network. The gateway (GW) is located in the upper part of the area. The physical radio range of each node -including the gateway- is defined as a circle with a diameter of 250 meter around the node. Each node has its own time base, i.e. it transmits HELLO packets with a random time offset between 0 seconds and the HELLO period, which is 1 second for the proactive and reactive approach. The interval time for the new HELLO approach is varied from 1 second to 30 seconds.

In order to compare the three discovery methods, the interval time of the gateway advertisements for the proactive method and the interval time of the solicitations for the reactive method are varied from 1 to 30 seconds.

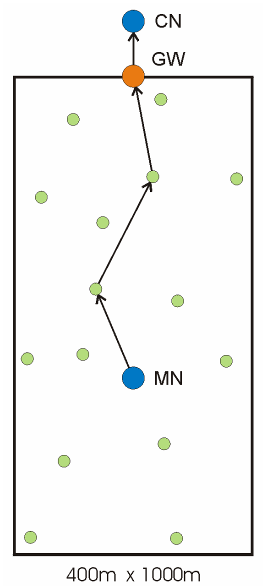

Fig. 1: Scenario topology

The intervals in which HELLO messages are sent have a strong influence on the neighbourhood management. A node recognises the loss of connectivity to a neighbour node after three HELLO intervals in which it does not receive HELLO packets from that neighbour node. Then it sets down all routes according to that neighbour and starts rediscovering procedures if that node is needed. This becomes important for the HELLO discovery algorithm for which the HELLO packets transmitting interval is a simulation parameter. For the proactive and reactive approach, this interval does not figure as a simulation parameter.

To investigate the gateway discovery time, the MN is switched on at t_{sim} = 100 seconds after the MANET is already established. At the same time a CBR data source at the MN starts creating packets addressed for the CN to trigger the MN's routing agent to perform the implemented algorithms.

More details on simulation parameters can be found in Table 1.

Number of nodes per MANET cluster	15, 60
Size of one cluster	400 meters x 1000 meters
Radio range of one node	250 meters
Total simulation time:	300 seconds
Simulated interval times	1, 2, 5, 10, 15, 20, 30
Traffic type	CBR
CBR packet size	500 Bytes
CBR packet generation	10 packets/second
Time out for local search request	1 second
MN's distance to gateway	600 meters
ALLOWED_HELLO_LOSS	3
HELLO_INTERVAL (proactive, reactive)	1 second
Number of averaged simulations	GW discovery: 200 (15 nodes) 100 (60 nodes) handover: 100 (15 nodes) 50 (60 nodes)

Table 1: General simulation parameters

The gateway discovery time is defined as the time that has passed since the MN was switched on until it gets a valid route to the gateway.

In all three discovery methods the MN starts searching the CN by sending a sequence of standard route requests [1]. Timeouts for these route requests are implemented according to [2] and have a maximum value of 5 seconds.

In the proactive method, when MN receives an advertisement, it either decides to accept or discard the information. It will accept the advertisement, if the MN has no route to a gateway, if the advertisement describes a shorter route to a known gateway, or if it was originated by the same gateway but with a higher sequence number. If the MN accepts the advertisement it will terminate all running local route requests, sets up or updates a route to the gateway where the advertisement was originated, starts another local route request with a timeout of 1 second and forwards the advertisement to other nodes.

This final local search route request is implemented for all three discovery methods to ensure that the MN does not send data packets to a gateway even if the corresponding node is located within the local MANET (all preceding route requests could have been sent from outside of any MANET, which may occur during a handover). After that final local search request expires, the mobile node will set the route to the corresponding node to default route as its next hop entry [2].

In the reactive algorithm the MN will primarily start to search its corresponding node locally within the MANET cluster. This is done by sending only three initial standard route requests [2]. After the third route request expires, the mobile node will send a gateway solicitation message that is answered by the gateway (if the random topology of the MANET cluster is able to give the MN a connection to the gateway). After receiving this gateway answer the MN will start a final local search for the CN as described above. If the solicitation is not successful, the mobile node sends another standard local route request with a timeout of 5 seconds, and tries again to find a gateway. The timeout for the solicitation request corresponds to the interval time of the reactive method in the following figures.

4.2 Simulation Results for the Gateway Discovery Time

The discovery time in the proactive approach is expected to be a half of the interval time, since the MN on average has to wait a half of the interval time to receive an advertisement. For the reactive method the discovery time should be a constant between 6.3 and 6.4 seconds, since the MN sends its first solicitation for a gateway after the three initial standard route requests, i.e. after a total of 6.3 seconds. The discovery time for the new HELLO algorithm depends on the number of nodes that are in radio range of the MN, and therefore of the total number of nodes in the cluster. The discovery time can be calculated using equation 1:

$$discovery\ time = \frac{A_{cluster} \cdot interval}{r_{radio}^2 \cdot num\ of\ nodes}[s] \quad (1)$$

The MN gets a valid gateway route by receiving the first HELLO_I packet and since the MNs are not synchronised in transmitting their HELLO_I packets the MN waits a very short time for its gateway information. Table 2 gives an overview of expected gateway discovery times.

	interval [s]			function: distime =
15 nodes	**1**	**10**	**30**	
Proactive	0.5	5	15	0.5 * interval [s]
Reactive	6.3	6.3	6.3	6.3s
HELLO	0.136	1.36	4.07	0.136*interval[s]
60 nodes				
Proactive	0.5s	5s	15s	0.5 * interval [s]
Reactive	6.3s	6.3s	6.3s	6.3s
HELLO	0.034s	0.34s	1.02s	0.034*interval[s]

Table 2: Expected values for gateway discovery time

Fig. 2 and Table 3 give the NS-2 simulation results for 15 MNs. At the proactive method we observed that especially for short interval times the simulated average discovery time is slightly smaller than half of the advertisement interval time. This can be explained by the mechanism a mobile node uses to forward advertisement messages. The forwarding is delayed by a short jitter of between 0 and 100 milliseconds to prevent collisions and therefore, more time elapses until every MN has forwarded the advertisement and the gateway information has reached all remote nodes. As a result, a MN waiting for an advertisement does not have to wait the maximum interval time. This behaviour becomes apparent with a look at the maximum discovery time. Simulations show a maximum discovery time of 0.878s and not the roughly expected 1s (for an interval of 1 second).

With 15 static nodes and the reactive algorithm the simulated average discovery times are as expected, because if the network topology is able to deliver the first solicitation to the gateway no further solicitation is needed and therefore, the interval time of solicitations is irrelevant. With 60 mobile nodes the average discovery time increases with increasing interval time (see Fig. 3). This is because a flooding of a network with a high density of MNs results in collisions of packets and therefore, the first solicitation might not arrive at the gateway. Consequently, the MN waits the whole interval time before it sends another standard route request of 5 second timeout and then retransmits a solicitation message.

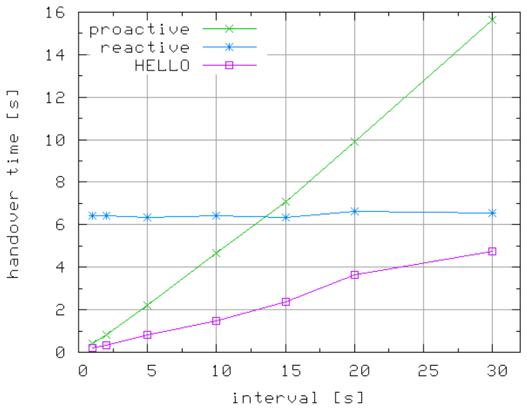

Fig. 2: Average gateway discovery time for 15 static MNs

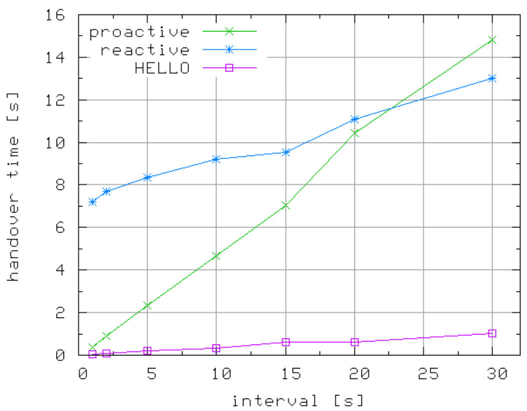

Fig. 3: Average gateway discovery times for 60 static MNs

The simulation results of the HELLO algorithm are as expected for 60 static MNs. With 15 static MNs the average discovery time is slightly longer than expected, because in many cases the first received HELLO packet by the MN does not contain information about the gateway (no I-flag is set). This fact is explained by the random positioning of the static nodes, which can divide the cluster into two sets, so that nodes of the second set do not receive information from the gateway. Thus, if the MN primarily receives HELLO packets from a node of the second set that has no gateway information, it has to wait for HELLO_I packets from nodes of the first set.

The conclusion is that the gradient in the proactive graph is larger than the gradient for the other two algorithms. Consequently, the proactive algorithm shows good performance for short intervals times and worst performance for long interval times, regardless of the number of nodes within the cluster. The discovery time for the reactive algorithm is basically caused by the sum of the first three standard route requests. This results in a relative long discovery time, even if the interval time of the solicitations is short. The HELLO algorithm shows the shortest discovery time, especially in networks with higher node density. Gateway discovery times have a strong influence on handover times. The next section deals with handover simulations and shows the performance of the three discovery methods.

	interval [s]			function: distime =
15 nodes	**1**	**10**	**30**	
Proactive	0.4s	4.6s	15.6s	0.5 * interval [s]
Reactive	6.4s	6.4s	6.6s	6.4s
HELLO	0.188s	1.49s	4.76s	0.165 * interval[s]
60 nodes				
Proactive	0.35s	4.65s	14.8s	0.5 * interval [s]
Reactive	7.2s	9.2s	13.0s	0.18 * interval [s] + 6.3s
HELLO	0.033s	0.33s	1.03s	0.034 * interval[s]

Table 3: Simulated values for average gateway discovery time

4.3 Simulation Results for Handover Simulations

To investigate the handover times of the MN which is moving between two clusters, the previous scenario has been extended by a second cluster. The second cluster has identical dimensions as the first cluster and is shifted horizontally by 700 meters, i.e. the gap between the two clusters is 300 meters. Each cluster has a gateway that is connected again to the CN. Because of the gap of 300 meters between the two clusters, the static nodes of one cluster cannot receive packets from nodes of the other cluster. However, the radio ranges of both clusters do overlap because every node has a radio range of 250 meters. Therefore, if MN performs a handover, it is able to continuously receive packets from nodes of one or both clusters.

At the beginning of the simulation run MN is located in the middle of the left cluster and starts its movement after both MANET clusters are in a steady state. It moves from its original position to the right cluster with a speed of 10 meters/second. The handover time is defined as the time difference between the receiving of the first data packet at the gateway of the second cluster minus the time when the last data packet has been received from the first gateway.

In general, clusters with more mobile nodes lead to shorter handover times. This may be explained by the fact that in clusters with less mobile nodes MN loses connectivity to the first cluster earlier and additionally has to move deeper into the second cluster to receive gateway information.

In the proactive and reactive approach HELLO packets are sent every second, but in the HELLO discovery implementation the HELLO interval is increased with the interval time. Thus, MNs take a longer time to sense the loss of connectivity to the gateway compared to the proactive and reactive method. This applies especially for large interval times (see Table 1 for details).

For the proactive algorithm the minimum handover time is expected to be slightly more than 1 second. The minimum time occurs if the MN receives an advertisement from the second gateway and changes the default route. Then it sends one local search request for the CN and if that local search is not successful the MN forwards its data packets via the new default route to the second gateway. The average handover time for proactive handovers is expected to grow linear with the gateway advertisement interval and with a gradient of 0.5. The offset of the handover time is expected to be smaller for 60 MNs than for 15 MNs. This is because of the more diffuse borders of the clusters when 15 nodes form one cluster.

In the reactive algorithm the minimum handover time is expected to be a constant between 9.5 and 10.4 seconds. The handover time is composed of three parts. First, there is a time span the MN needs to detect the loss of connectivity to its next hop entry in the routing table for the gateway route and therefore, to the default route. The MN detects this loss if it does not receive HELLO packets from its next hop entry for three HELLO interval times, which equals 3 seconds. The last HELLO packet from the next hop entry pointing to the gateway may be received between 0 and 0.9 seconds before leaving the physical connectivity and therefore, the time data packets are received by the old gateway may vary from 0 seconds to 0.9 seconds. Thus, the MN needs between 3.0 and 3.9 seconds until it starts the rediscovery process for a gateway. The second part of the minimum time is the total of the three standard route requests which sum up to 6.3 seconds. After that the MN sends a solicitation and gets a gateway and default route. This process requires just a few milliseconds. Finally, the MN sends a local search route request with a timeout of one second to ensure that the CN is not located within the second cluster. Mean handover times for the reactive method are expected to increase linearly with the interval time and an offset according to the gap between the two clusters.

For the HELLO algorithm the shortest handover times are expected for short HELLO interval times. With increasing interval time and therefore, increasing HELLO intervals, the MN needs more time to detect the loss of connectivity. Thus, a linear increase in the average handover time is expected.

The NS-2 simulation results for the described scenario are given in Fig. 4 and Fig. 5. The two figures show the average handover time for the three algorithms for 15 and 60 static nodes per cluster. The gradient of the proactive algorithm is about 0.5 in simulations with 15 and 60 nodes. This is according to the simulation results of the gateway discovery time. Additional, for 15 nodes, an offset of approximately 6 seconds is observed compared to simulations with 60 nodes per cluster. This offset is explained by the more diffuse edge of the service area of the cluster with 15 nodes and therefore, the average radio gap between the two clusters is increased.

The simulation results of the reactive algorithm show a handover time offset of about 2 seconds and a small positive gradient of 0.2. The positive gradient is explained by the fact that the first solicitation of rediscovering the gateway is not successful due to gaps in the network topology.

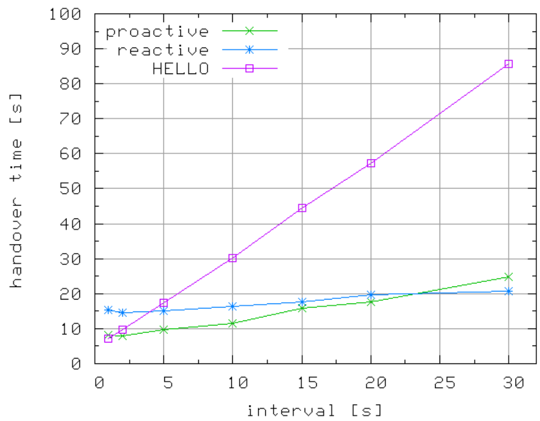

Fig 4: Average handover time for 15 static MNs per cluster

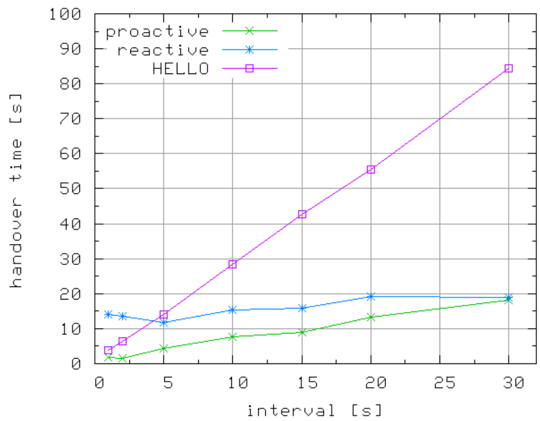

Fig 5: Average handover times for 60 static MNs per cluster

Then the MN has to wait another interval time before trying to find the gateway again.

The results for the simulations on the HELLO algorithm show a handover time offset which is reduced with increasing number of MNs. As expected the handover time is short if short HELLO interval times are used. However, the expected linear growth with the handover interval time is confirmed. The bad performance of the HELLO algorithm for longer interval times is mainly driven by the mechanisms by which AODV detects link losses.

Thus, only short HELLO interval times should be used for any ad-hoc routing protocol.

5. CONCLUSIONS

In this paper we have investigated a gateway discovery algorithm for ad-hoc networks based on modified HELLO packets of the AODV protocol. The new algorithm has been compared to the common proactive and reactive gateway discovery algorithms with the aid of NS-2 [5] simulations. The HELLO algorithm shows best performance in the average gateway discovery time when it is compared to the proactive and the reactive discovery algorithms. This can simply be explained by the fact that a mobile node receives gateway information with the first modified HELLO packet, i.e. the first HELLO_I packet. Since all MNs which can reach the gateway via other MNs carry the gateway information within their HELLO_I packets, and because the MNs are not synchronized in time, the time interval between received HELLO_I packets is reduced with increased number of MNs in the cluster.

When handover times are investigated, the HELLO algorithm shows worst performance for larger interval times of the HELLO packets. The reason is that the neighbourhood management in AODV uses HELLO packets to detect link losses, and increased interval time in the HELLO algorithm degrades the performance of the algorithm. This is because the proactive and reactive algorithms still use standard HELLO packets with an interval time of 1 second to detect link losses. Therefore, the HELLO algorithm should only be used with an interval time of 1 second. Then a small gain compared to the proactive algorithm can be achieved.

It should be noted that due to the fact that no additional messages are needed to discover the gateway, the overhead for the HELLO gateway discovery algorithm is zero. This is in contrast to the proactive and reactive algorithm which are based on gateway advertisement and MN solicitation messages

The investigations on the three gateway discovery methods lead to the following statements, which may improve their performance. Long gateway discovery times in the reactive approach are caused by three standard route requests before solicitation messages are sent out by the MN. A performance improvement is expected if the MN generally sends a new modified route request for the CN with the I-flag set and thus indicating that it is searching a gateway. So, if a gateway is reachable via the MANET it will answer to that request. If the CN is located within the MANET it will answer too. With this minor modification a MN will only send a single route request instead of four requests with the current solution.

Short discovery times for the HELLO algorithm are caused by the fact that HELLO messages of the MNs are not synchronised in time. Therefore, a performance improvement of the proactive algorithm is expected if all nodes within the MANET cluster delay the forwarding of advertisements randomly between 0 seconds and the interval time. Then the discovery time is expected to decrease with a higher number of mobile nodes in the cluster. Furthermore, advertisements should only be forwarded by a MN if it is using the gateway where the advertisements were originated at. Thus, the routing overhead is expected to be reduced if clusters do overlap. To further improve the performance of discovery algorithms, the gateway information could even be included into an additional IPv6 header of data packets.

6. ACKNOLEDGEMENT

This work was supported by T-Systems under the German research project ”IPonAir” [10], partly funded by the German Ministry for Education and Research (BMBF) and the Hessian Ministry of Research and Arts (HMWK).

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