A Novel Multicast Tree Construction Algorithm for Multi-Radio Multi-Channel Wireless Mesh Networks

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Abstract

Many appealing multicast services such as on-demand TV, teleconference, online games and etc. can benefit from high available bandwidth in multi-radio multi-channel wireless mesh networks. When multiple simultaneous transmissions use a similar channel to transmit data packets, network performance degrades to a large extant. Designing a good multicast tree to route data packets could enhance the performance of the multicast services in such networks. In this paper we want to address the problem of multicast routing in multi-radio multi-channel wireless mesh networks aiming at minimizing intermediate nodes. It is assumed that channel assignment is known at prior and channels are assigned to the links in advance. Aiming at constructing multicast tree with minimum number of intermediate nodes and minimum number of interfered nodes we propose a heuristic algorithm called Maximum Multicast Group Nodes (MMGN). Simulation results demonstrated that our proposed method outperforms LC-MRMC algorithm in terms of throughput and packet delivery ratio.

Keywords: Wireless Mesh Networks, Multicast, Multi Radio Multi Channel, Channel assignment.

1. Introduction

Wireless mesh networking is emerging as a promising technology for low-cost, ubiquitous broadband Internet access via reduced dependence on the wired infrastructure. In a wireless mesh network, a collection of stationary wireless access routers provide connectivity to mobile clients akin to access points in a traditional wireless LAN; but access routers communicate with each other wirelessly, potentially over multiple hops; a small fraction of those access routers are wired to the Internet and serve as Internet gateways for the rest of the network. Mesh networks based on commodity 802.11 hardware and employing self-configuring ad hoc networking techniques can offer wider coverage with less expense and easier deployment. Furthermore, inherent redundancy in the mesh topology enhances reliability. Consequently, mesh networks enable a number of new application scenarios, including community wireless networking to provide affordable Internet access especially beneficial for low-income neighborhoods and scarcely populated areas [1].

Multicast routing is a key technology that facilities data transmission to a group of recipients. Due to the broadcast nature of air medium, wireless

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communications are suitable for performing multicast routing. In multicast transmissions each node could transmits data to neighbor nodes just by one transmission. In other word each node could reach other nodes by one transmission. Most of multicast services need a high available bandwidth to deliver data without a high error rate [2].

When developing multi cast trees in WMNs, Shortest Path Trees (SPT) are seen to be more advantageous than Minimum Number of Transmissions (MNT) or Minimum Steiner Trees (MST). SPTs by their nature will have a minimum delay. However, these tend to assume a fixed transmission rate based on the maximum available physical layer (PHY) rate (e.g. 11Mbps for 802.11b networks). In reality, the transmission rate is based on Packet Error Rate (PER) which is related to the signal strength (which in turn is related to the distance between nodes), resource utilization and channel error model. In shortest path tree algorithms the path is created by finding the most direct route from source to destination. Hence, these algorithms tend to use long links resulting in lower rates. In addition to this, many multicast routing algorithms assume a link cost of one and hence ignore link metrics which may have a significant impact on performance [3].

The problem of efficient multicast routing in a wired network has been studied in depth. Several multicast routing protocols have been proposed for wired networks such as DVMRP (Distance Vector Multicast Routing Protocol), MOSPF (Multicast Extensions to Open Shortest Path First), PIM (Protocol Independent Multicast), and CBT (Core-Based Tree)[4]. Although these protocols work well in wired networks, they are not suitable for wireless environments. In wireless networks, bandwidth is a scarce resource and wireless links are more error-prone than their wired counterparts.

Due to high available bandwidth in Wireless mesh networks, they are apt for performing multicast transmissions. WMN includes a set of mesh routers which are connected in multi-hop manner. To relay the received traffic from internet, at least one node act as gateway. Gateway is responsible to deliver data to mesh routers which are intermediate nodes in the mesh topology and try to deliver data to the mesh clients [1, 5].

Multicast routing in such networks is highly related to channel assignment strategy. Network available bandwidth is the most factors for conducting multicast transmissions but it could be decreased by wireless interference. Using multiple radio interfaces and use multiple channels could increase available bandwidth in WMNs [2].

We can have different approaches to constructing a channel assigned multicast tree. We can assume that multicast tree is known at prior and assign least interfered channels to the tree links or it could be assumed that channel assignment is known and we must do multicast routing. As a last approach we can take both problems into consideration and solve both problems jointly.

Our approach falls into second category in which we have a channel assigned network topology and we want to find routes to the multicast receivers in a way that network interference is minimized and as a consequence the network capacity is maximized. After constructing multicast tree, we take a heuristic method for multicast tree construction in wireless mesh network.

Compared to existing multicast routing approaches our contributions for multicast tree construction can be listed as follows:

- Designing a new method to construct multicast tree in a channel assigned network.
- Introducing a new concept called multicast group nodes (MGN) to support all multicast receivers.

The rest of the paper is organized as follows: Section 2 surveys the previous related works. The details of the proposed methods are described in section 3. Section 4 evaluates the performance of our proposed algorithm. Section 5 illustrates the experimental results. Finally, section 6 concludes the paper.

2. Related Works

Authors in [6], a greedy-based heuristic algorithm is proposed to build multicast trees with the minimal number of forwarding nodes for a single-channel WMN. These trees are referred as MNT trees. The MNT tree is built without considering the minimization of maximum path delay of the tree. The channel assignment problem for minimizing the interference caused by adjacent-channel and co-channel is the key problem for WMNs. Most channel assignment algorithms published in the literature are designed for unicast. There are only a few channel assignment algorithms proposed for multicast. In reference[7], a channel assignment algorithm called BFVC based on greedy vertex coloring strategy is proposed for a given multicast tree. One problem with BFVC algorithm does not take the wireless broadcast advantage (WBA) into account. In addition, since only orthogonal frequency channels are used for channel allocation, a lot of bandwidth resource is wasted. Most algorithms designed for MCRM WMNs perform routing first, then followed by channel assignment procedure [8, 9]. In contrast, the "channel assignment first, routing second" approach is considered in reference [10]. Authors goal is to construct a multicast tree for a given MRMC network with allocated channel assignments so that the amount of network bandwidth consumed by the routing tree is minimized. However, no study on channel assignment or transmission interference on links is reported. In reference [11], an algorithm named MCM is used to construct multicast trees with minimum relay nodes and minimum hop counts for distances between source and destinations. Based on the concept of interference factor (IF), a channel assignment procedure is also developed for allocating channels for MRMCWMNs. However, the MCM algorithm suffers from the hidden channel problem by considering interference from only one-hop neighbors, which is then solved by a channel assignment algorithm named M4 presented in reference [8]. In M4 algorithm, the interference from one-hop and two-hop is taken into account when the optimization function is derived for minimizing the interference. All the orthogonal and partially overlapping channels are used in both MCM and M4 methods. In conclusion, the central goal of both the MCM and M4 algorithms is to determine minimum interference multicast trees for MCRM WMNs. However, it is easy to have a situation that interference may occur from a neighbor that is more than two-hop away from the current node as long as $d \leq IR$, where dis the distance between them and IR is the interference range. In this paper, therefore, we are interested in constructing an interference-free multicast tree for our MRDCM problem using all the available channels based on the study of IF presented in references [8, 12]. In reference [13], authors investigate the characteristics and behavior of transmissions with different rates in wireless multi-hop mesh networks. They proposed a parallel Low-Rate Transmissions (LRT) and Alternative Rate Transmissions (ART) to explore the advantages of MRMC under the constraint of limited channel resources. A novel Link-Controlled Multi-Rate Multi-Channel (LC-MRMC) multicast algorithm was also presented to extend wireless multicast coverage with high throughput. The main objective of this study is to support all clients who can successfully receive data streams from the multicast source. This approach is very different to the prior studies described above.

In reference [14], the authors utilized integer programming to formulate multicast routing and channel assignment in MRMC WMNs, that is, with the goal of minimizing total utility cost of path, the problem is solved along with constraints. The proposed mechanism is named as utility-based multicast routing and channel assignment (UBMR-CA). The utility weight metric for a link is defined as:

$$UWM = \sum_{1 \le i \le n} \sum_{1 \le j \le n} \left(U_{i,j}^{init}\right) - \left(\tilde{t} \sum U_{i,j}^{new}\right) \quad (1)$$

$$U_{i,j}^{l} = \sum_{1 \le i \le n} \sum_{1 \le j \le n} b_{i,j,p}^{l} \times \left(C^{l} - lo^{l}\right) + \sum_{l,l' \in E} IM_{l,l'} \quad (2)$$

Where $U_{i,j}^{init}$denotes the initial utility generated, $U_{i,j}^{new}$ is the new utility generated. $\tilde{t}$ denotes the time taken to generate the new utility for channel assignment. $b_{i,j,p}^{l}$ is a binary variable whose value depends on whether link *l*is on the path or not. C^{l} is capacity of link l. lo^{l} denotes the load on link *l*. $IM_{l,l'}$ is the interference matrix.

In reference [15] authors proposed a learning automata based multicast routing (LAMR) protocol to solve the problem of JMRCA for MRMC WMNs. LAMR runs on different network interface cards (NICs) independently in parallel. Operation of LAMR for each NIC is composed of two stages: in the first stage, minimum end-to-end delay multicast tree is constructed, which is carried out through sending out routing request and reply messages channels are selected based on action probability vector (APV); in the second stage, the source node sends out routing request messages again along the paths constructed in the first stage, channels are changed and the overall tree contention of the newly constructed tree is computed. If its value is smaller, the newly constructed multicast tree is formed. A stable multicast tree is derived after a few runs. However, little about update process for APV and how to select channels is provided in[15].

Authors in [16] proposed a cross-layer and load-oriented (CLLO) algorithm to solve JMRC problem with the goal of maximizing the number of served subscribers in MRMC WMNs. In CLLO, multicast tree is generated in a top-down manner, at first the tree only covers the gateway, and then one node is added to the tree at a time. If a link whose sibling links are already in the tree can be found, it is added to the tree; otherwise a feasible link which can be allocated with at least one interference-free channel if it is added into the tree should be found out; or else channels allocated to links in the tree are changed until at least one feasible link can be found. This process repeats until all multicast receivers are included in the tree or none feasible crossing link can be found.

3. Proposed Approach

This section presents the proposed method for multicast tree construction in wireless mesh networks. This method is called MMGN, which is proposed to construct multicast trees with minimum number of intermediate nodes and covering all multicast receivers. What follows is a description of the proposed approach in detail. In our MMGN algorithm, a multicast tree is generated in a top–down manner. Initially, the partial multicast tree T contains only one node (the gateway). We then add uncovered nodes to tree one at a time.

3.1. Notations and Model Assumptions

The proposed algorithm assumes that all mesh routers are distributed randomly on a specific area. Each router is equipped with multiple radio interfaces all of which use Omni-directional antennas, and have identical transmission and interference range. The network is modeled by an undirected graph G (V, E), where V represents a set of nodes in the network and E is the set of undirected edges between the nodes. The edge connecting two nodes u and v implies that u and v are located in transmission range of each other and a channel could be assigned to that edge. Also, we use the term “Maximum Multicast Group Nodes” (MMGN) to represent maximum multicast receivers that a node can support.

3.2. Maximum Multicast Group Nodes (MGMN) Algorithm

This section provides details of the proposed work. As presented in Fig. 1, the algorithm starts by adding source node S to the multicast tree, then each node specifies the maximum multicast group nodes set that it could cover. We call this set MMGN. For this purpose, the MMGN set of all multicast receivers is set to their ID (line 1-4). Then, each node checks if there is a link to upper level nodes. If the answer is positive, add the link to the tree.

$$\mathrm{MTM(u) = |MMGN(u)| - interference(u)} \tag{3}$$

For example consider Fig. 2 that is traversed in a bottom-up manner using the proposed algorithm. As it is noted, in each iteration nodes in the same level could specify their supported multicast receivers. After determining MMGN set for each node, the algorithm specifies adding which nodes to the multicast tree results in maximum capacity for the network and covers all multicast receivers. Multicast source is the first node that is added to the tree. Then, child nodes of the multicast source will be sorted based on the metric defined in (1).

Multicast Receiver Identification Algorithm (G (V, E), MG)

```
{
 1.For (∀ u ∈ V )
 2.{
 3.   If (u ∈MG) {MMGN (u) = {u} ;}
 4.}
 5.For (i = Max-Level ; i>= 0 ; i--)
 6.{
 7.     For (∀ u ∈ V & level (u) == i)
 8.     {
 9. If(∃ v ∈ V & if there is a e(v,u)&level(v)< Level(u))
 10.    {
 11.  If (e(v,u) is verified using eq.(1))
 12.  {MMGN(v) = MMGN  (v)∪MMGN (u); }
 13.      Else { remove e(v,u); }
 14.     }
 15.  }
   }
```

Fig. 1. Multicast receiver identification algorithm

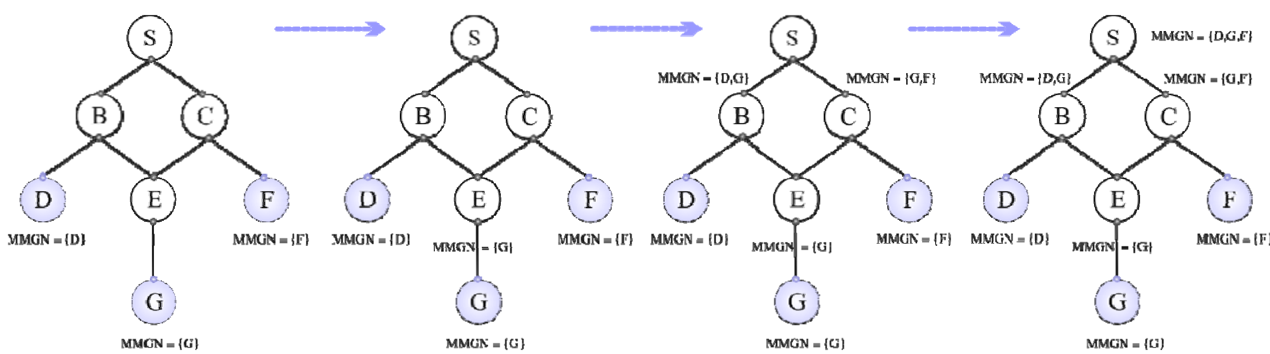

Fig. 2. Multicast tree construction process

In the equation (3), Interference (u) is the number of one-hop and two-hop neighbors of node "u" that a channel assigned to which could be computed as follows [17].

$$ID(n_k, n_p) = \begin{cases} \dfrac{IF(C_{n_k}, C_{n_p}) \times R}{Dist(n_k, n_p)} & if\ IR \geq 1 \\ 0 & else \end{cases} \tag{4}$$

Where $ID()$ is the function to estimate the interference degree between node p and one of its preceding nodes. Unlike the previous approaches the distance effect is particularly considered in the interference estimation. C_{n_k} is the already used channel of preceding node n_k, and C_{n_p} is the channel assumed to be used by node p, $IF(C_{n_k}, C_{n_p})$ is the interference factor for the channel gap between C_{n_k} and C_{n_p}. $IF(C_{n_k}, C_{n_p}) \times R$ can also represent the interference distance (range) between node p and preceding node n_k. Note that R is the transmission range of a node. In (4) the function $Dist(n_k, n_p)$ is used to calculate the location distance between node p and preceding node n_k. If the ratio of $IF(C_{n_k}, C_{n_p}) \times R$ to $Dist(n_k, n_p)$ is less than 1, it represents that the interference distance is less than the location distance. In such case, no interference exists between node p and preceding node n_k.

It is better to select a node to be on-tree node that its MTM value is more than other same level nodes. In each level it is checked if adding the node to the tree does not generate a loop and also it minimizes the intermediate nodes.

Tree Construction Algorithm (G (V, E), MS, MG)

```
{
   Tree-members = {S} ;
   For (Each node u at level i based on |MMGN (u)|& if u ∈ Tree-members& if u ∉ MG)
   {
     For (v ∈ u → childes)
     {
       interference=Find-Potential-inter-Nodes
   MTM = α × |MMGN(v)| − β × interference
     }
   Sort u → childes based on their MTM value in descending order
   P = MMGN (u); N = { } ;
   While (|p| > 0)
   {
    accept = true;
     Select a node r from u → childes based on descending order which is ∉ Tree-members
     For (∀ k ∈ N)
     {
   If(MMGN(r) ⊆ MMGN(k)){accept = false ;}
     }
     If (accept == true)
    {
    Add r to N ;
   p = p – {MMGN(r) ∪ Tree-members} ;
        }
   }
   Tree-members = Tree-members ∪ N;
   }
}
```

Fig. 3. Multicast tree construction algorithm

Fig. 4. Shows an example for tree construction using multicast tree construction algorithm. As it can be concluded from the figure, a tree with minimum number of intermediate nodes is constructed.

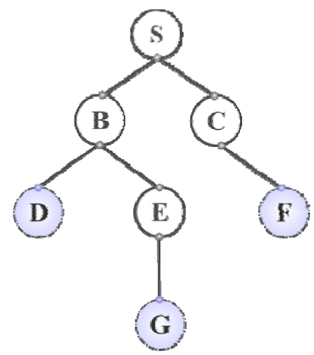

Fig. 4. The resultant multicast tree from tree construction algorithm

4. Performance Evaluation

This section provides performance evaluation of the proposed algorithm and the simulation results are presented. We use OPNET Modeler [18]to evaluate the performance of the proposed algorithm and comparing it with LC-MRMC algorithm. We have conducted several simulations to verify effectiveness of the proposed algorithm. We use the following metrics to measure the performance of our proposed work.

- **Average end-to-end delay.** The ratio of the number of delivered data packet to the destination. This illustrates the level of delivered data to the destination.
- **Average throughput.** Average rate of successful message delivery over a communication channel.

Our simulations are based on IEEE 802.11b CSMA/CA medium access control because this is a widely accepted radio technique for WMNs. each mesh router has two radios. There are 11 available channels and transmission power is 20dB and it is fixed for all nodes. Transmission rang and interference ranges are 250 and 500 meters, respectively.

5. Experimental Results

In this section we want to evaluate our proposed approaches in terms of end-to-end delay for a network with different number of multicast receives and different simulation times. It is expected that our proposed method has a better performance against other work, because it tries to choose the links with minimum interference. So if the interference is minimized then end-to-end delay will be minimized as so. Also our method computes the interference caused by partially overlapping channels. Fig.5 and 6 show the obtained results for end-to-end dely. And Fig. 7 and 8 show network end-to-end delay in different simulation time.

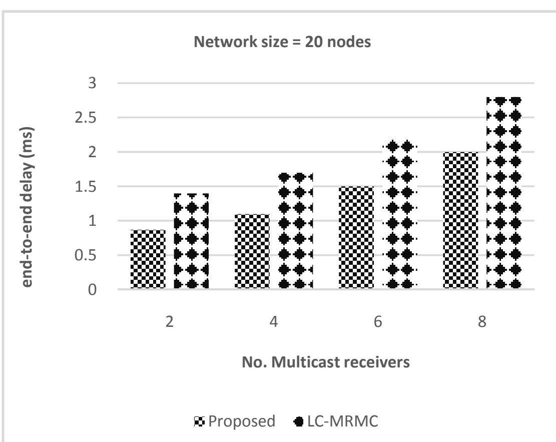

Fig. 5. Average end-to-end delay for a network with 20 nodes and different number multicast receivers

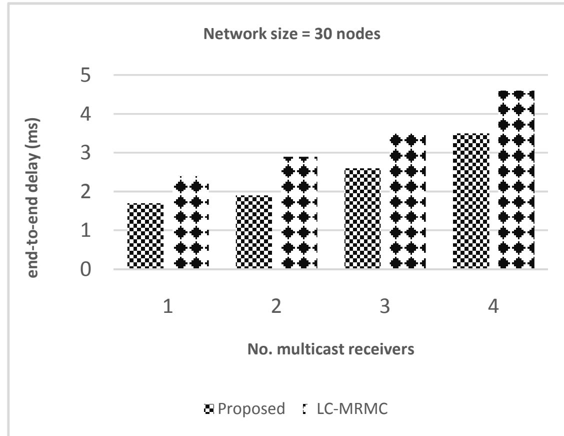

Fig. 6. Average end-to-end delay for a network with 30 nodes and different number multicast receivers

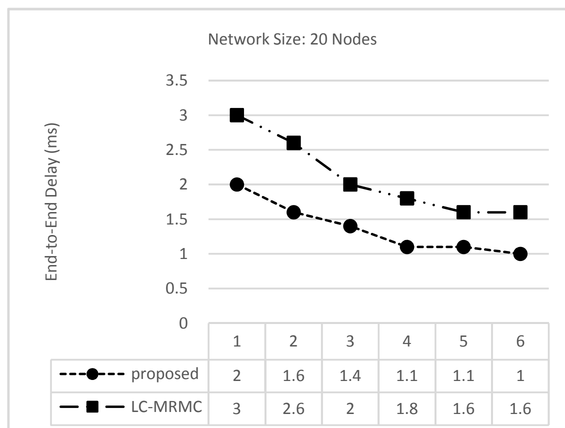

Fig. 7. Average end-to end delay for a network with 20 nodes in different simulation times

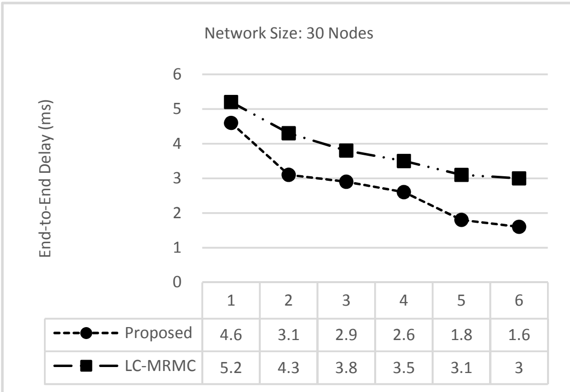

Fig. 8. Average end-to end delay for a network with 20 nodes in different simulation times

Now we want to compare our proposed algorithm withLC-MRMC in terms of throughput. In this series of experiments we want to evaluate the performance of our proposed algorithm in terms of throughput. We have to scenarios includes 20 and 30 nodes in the network. We want to evaluate the performance of the methods when number of multicast receivers is changes. Fig. 9 shows the results of the experiments for a network with 20 nodes and different number of multicast receivers. Also Fig. 10 illustrate the experimental result for a larger-scale network with same configurations.

It is worth to noting, our proposed approach has a lower time complexity in comparison with LC-MRMC because the proposed work does not need any prior information before constructing the tree, but LC-MRMC need some pre computations such as BFS algorithm to traverse network nodes before constructing the multicast tree.

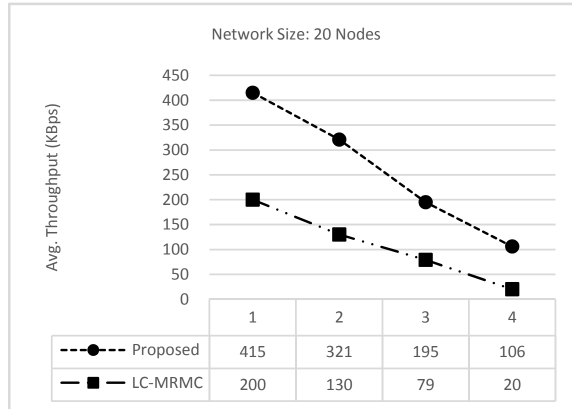

Fig. 9. Average throughput for a network with 20 nodes and different number of multicast receivers

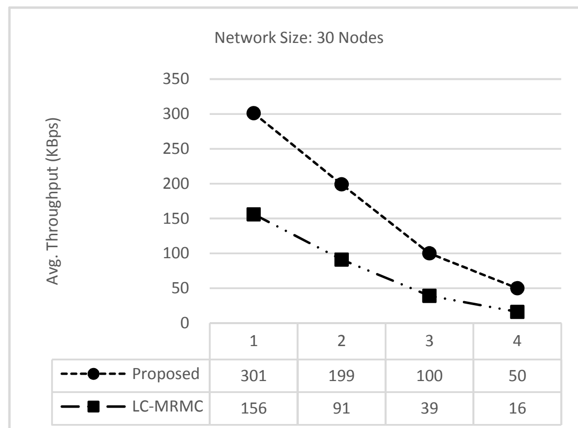

Fig. 10. Average throughput for a network with 30 nodes and different number of multicast receivers

6. Conclusion

In this paper, we addressed the problem of multicast tree construction in MRMC WMNs. Also we investigated the impact of using partially overlapping channels to choose the routes with smaller interference. Simulation result shows that the proposed algorithm could achieve a better performance compared with LC-MRMC algorithm in terms of average end-to-end delay and average throughput.

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