Minimizing Information Asymmetry Interference in Multi-Radio Multi-Channel Wireless Mesh Networks (MRMC-WMNs)

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ABSTRACT: *Multi-radio Multi-channel (MRMC) Wireless Mesh Networks (WMNs) in recent years have become a preferred choice for end users as they are reliable and extend the network connectivity on the last mile. MRMC-WMNs have already been deployed at various places but still WMN faces link interference issues i.e Information Asymmetry (IA), Near Hidden (NH) and Far Hidden (FH) terminals. These interference issues have made the capacity of MRMC-WMNs limited. To maximize the MRMCWMN capacity in this paper we are presenting an algebraic channel assignment model that minimizes information asymmetry (IA) interference. Our proposed model optimally assigns IEEE 802.11b/g non-overlapping channels (1,6 and 11) to various links of MRMC-WMN. For extensive simulations we consider various MRMC-WMN topologies. We compare the results of both the scenarios where our algebraic optimization model has been applied with those where the model has not been applied. Simulation results show that our proposed optimization model maximizes the capacity of MRMC-WMN up to 8%.*

Keywords: MRMC-WMN, Information Asmmetry IA), Non-overlapping Channels

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1. Introduction

Wireless Mesh network is a promising technology for providing reliable, scalable and affordable low-cost solutions for a various applications such as broadband wireless internet access in developing parts of the world. Multi-Radio Multi- Channel Wireless Mesh Networks also called MRMC-WMNs consist of wireless mesh routers, mesh clients and mesh gateways. In WMN the nodes are static unlike the mobile adhoc network. The gateway nodes are used to relay network traffic towards other networks and work as a bridge between wireless mesh network and other heterogenous networks. A WMN can be divided into three levels [1]. First level consists of gateways. On the second level we have wireless mesh routers which works a backbone to relay traffic inside the WMNs on behalf of the mesh clients or end users. These mesh routers are also called mesh nodes while the end users are the actual senders and consumers of data (third level). The complete architecture of WMN is illustrated in Figure 1. Mesh routers or nodes can only communicate if they operate on same IEEE 802.11b frequency channel.

Depending upon the radio to channel configuration also called channel-radio mapping, mesh networks can be classified into i) single-radio single-channel (SRSC), ii) single-radio multi-channel (SRMC), and iii) multi-radio multi-channel (MRMC) wireless mesh networks. In a SRSCWMN, all mesh nodes in WMN are configured to use thesame wireless frequency channel. This ensures network connectivity;however, all the nodes try to access the same frequency channel that affects network capacity.

Therefore, interference minimization is a major issue in such networks [11].

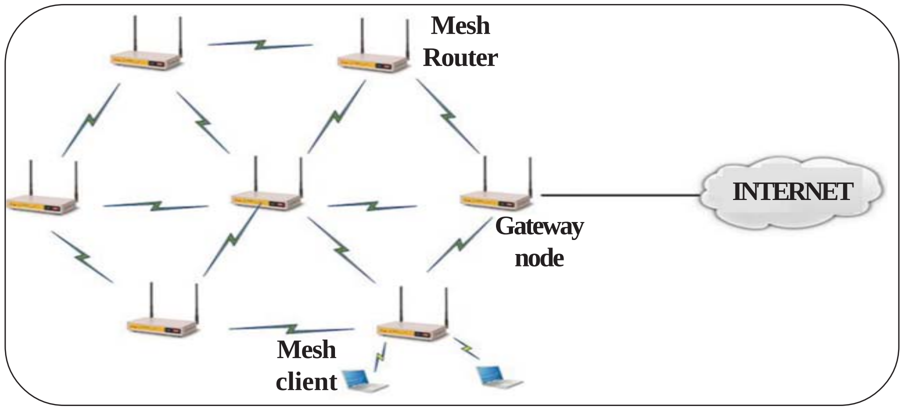

Figure 1. Wireless Mesh Network

In case SRMC WMNs, Mesh routers nodes can't utilize multiple channels efficiently. The single radio need to be switched very frequently among frequency channels due to dynamic traffic demands [1]. This switching causes considerable delays during data transmission. These delays can be in milliseconds and even leads to link disconnection. MRMC on the other hand is used in current deployments is very useful. In multi-radio environments each node is equipped with multiple radios and multiple frequency annels can be assigned to same node at the same time that leads to greater network capacity and throughput. Keeping the advantages of MRMC architecture in this paper we consider multi-radio architecture.

In WMNs every node (mesh router) has its own transmission and carrier-sensing range. Two nodes communicate only if they are in the transmission range of each other and operate on the same frequency channel. Apart from transmission range every node in a WMN has a carrier-sensing range. Inside carrier-sensing range nodes can create interference if they are sending data and operating on the same frequency channel. When interference occurs it causes transmission losses and also degrades WMN performance.

1.1 IEEE 802.11b/g Frequency Spectrum

In this paper we are considering IEEE 802.11b/g technology for channel assignment as most of the current deployments are IEEE 802.11x based. Among all the versions of of IEEE 802.11x the most widely used is IEEE 802.11b/g Frequency Spectrum. It has 11 frequency channels available for use out of 14 channels in ISM band (2.4GHz). Only three channels 1,6 and 11 are considered non-overlapping in IEEE 802.11b/g frequency spectrum and we are using these three orthogonal channels for channel assignment in this research work. IEEE 802.11b/g Frequency Spectrum is presented in Figure 2.

1.2 Interference in Wireless Mesh Networks

Interference in wireless mesh network has been categorized as coordinated (*CO*) and non-coordinated (nCO) interference [2]. Two links are called coordinated (*CO*) interfering links if source nodes of these interfering links are in each other's carrier-sensing range. Similarly in case of non-coordinated (*nCO*) interference, the source nodes of two links need not to be in carrier-sensing range of each other. Non-coordinated (*nCO*) interference is further divided into three types by Guaretto et. el[2] i.e.

i) Information asymmetry, ii) Near-hidden terminal and iii) Far-hidden terminal.

The focus of this research paper is to minimize information asymmetry interferec in MRMC-WMN by utilizing non-overlapping channel assignment of IEEE 802.11b technology. Figure 2 presents coordinated (*CO*) and information asymmetry interference links. If two links $L1(s1,d1)$ and $L3(s3,d3)$ are active on the same channel then for information asymmetry (IA) interference the following relationship is true. If d represents the physical distance among mesh nodes then:

- $d\,(s1, s3) > CR$
- $d\,(d1, s3) < CR$
- $d\,(s1, d3) > CR$

Source nodes $s1$ and $s3$ are outside each other carrier sensing ranges Cs. Similarly $s1$ and $d3$ are also outside each other carrier-sensing range but $s3$ and $d1$ are inside each other carrier-sensing ranges. In such case flow on $L1(s1, d1)$ can be reduced due to interference from $L3(s3,d3)$.

To minimize IA interference channel assignment in WMN, performs very important role. For optimal channel assignment and minimizing IA interference various channel assignment models and algorithms were proposed which is discussed later in this paper. Although there are multiple issues faced by a MRMC-WMNs i.e. node deployment, channel assignment, link scheduling and routing but channel assignment can perform a significant role in maximizing WMN capacity by minimizing interference among WMN links. For channel assignment the radio technology we use in this paper is 802.11b as discussed earlier. Any two frequency channels separated by at least 25MHz frequency are termed as nonoverlapping (also called orthogonal channels) and currentlythey are in use [3]. Keeping in view their use in this paper we are presenting an optimization model for channel assignment.

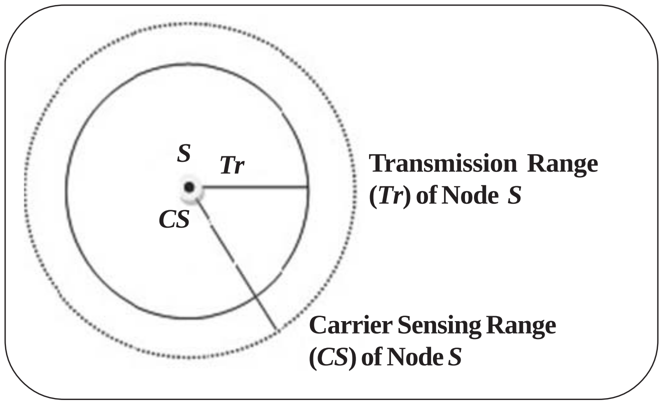

Figure 2. Coordinated interference: The source of $L2$ is inside the carriersensing range of $L1$. Both the links can share channel 1

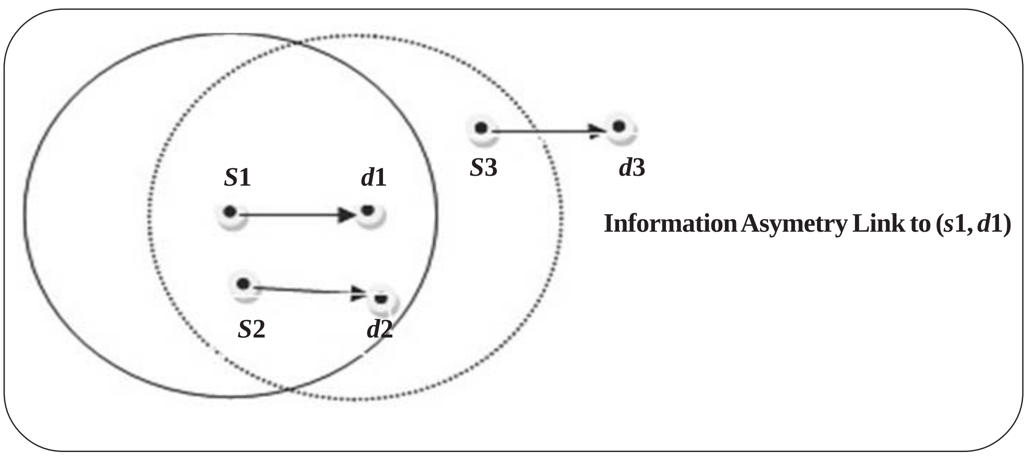

Figure 3. Information Asymmetry Interference(nCO) Categories

1.3 Research Contribution

Our research contribution is as follow:

• We propose an algebraic optimization model for optimal channel assignment strategy. Channel to radio binding is done according to the optimization model results.

• Second we analyze the performance of our channel assignment strategy in those scenarios where information asymmetry interference is high in various MRMC-WMN topologies.

• In the end we verify our optimization model results through extensive simulations. Our simulation results also show that the channel assignment strategy given by our optimization model performs better in minimizing information asymmetry interference.

2. Literature Review

The problem of interference has been discussed in different studies already. Garetto et al. [2] divided interfering links into two broad categories. One of them is Coordinated (*CO*) and the second is non-coordinated (*nCO*) links. The author had further classified *nCO* interference as Information Asymmetric (IA), Near- Hidden (NH) and Far-hidden (FH) interfering links. The author in his research has derived conditional packet loss probabilities of WMN links under each category and classification of interference. After comparison the author has proved that non-coordinated link interference results in higher transmission losses as compared to that coordinated interference.

A. Raniwala et el. [7] illustrated an iterative approach for solving the joint routing and channel assignment problem. Their proposed algorithm calculates both a routing scheme as well as channel assignment scheme in MRMC-WMNs. Vibhav et el. [5] presented joint channel assignment and flow allocation for MRMC-WMNs as a Mixed Integer Linear Program (MILP). They have done channel allocation statically and their objective was to enhance end-to-end throughput by utilizing both non-overlapping and overlapping channels. Further the channel assignment problem has been formulated by Ali cherry [8] and Kodialam [9] by using linear programming (LP) with constraints on interference and fairness, that is NP hard. Fawaz Bokhari in [11] described an Ant Colony Optimization (ACO) scheme in which smart ants called agents perform both routing and channel assignment in WMN to solve stochastically a dynamic network optimization problem . Recently Sadiq Shah et el. [12] proposed an optimization model for minimizing non-coordinated interference.

Naveed [6], has presented the idea of dynamic channel assignment algorithm called LYCAS and presents an channel assignment optimization model for maximizing the network throughput. The model also minimizes the non-coordinated (*nCO*)interference and the author showed that (*nCO*)interference is more harmful than coordinated interference. However the author has taken two decision variables which are difficult to solve. In this paper we are extending the work done in [6] using only one decision variable with the goal to maximize network capacity and minimize information asymmetry interference.

3. Proposed Optimization Model

3.1 Problem Formulation

In this we present our proposed model that is non-linear optimization model. The proposed model consists of one decision variables and one objective function with the objective of maximizing WMN capacity.

We consider in this paper a directed graph $G = (V, E)$ consist of V wireless mesh nodes and E mesh links or edges. K is the set of all available IEEE 802.11b frequency channels. k is the total number of frequency channels that is 11. C_{c_i} represents the total capacity of each frequency channel. Further $I(v_j)$ is the set of directional links incident on node v_j. The number of interfaces on each node v_j is $n(v_j)$ which is ≥ 2 which is an assumption. $IA(e_j)$ represents the set of all information interfering (IA) links of a link e_j . $co(e_j)$ is set of all information interfering edges of e_j . Flow over link is $f(e_j)$. $x(e_i, c_j)$ is representing the binary decision variable that is 1 if link e_i in active on channel c_j otherwise it is 0. $\lambda(e_i)$ is the fraction of traffic flow on any edge (e_j). Carrier-sensing or interference range is represented by $r\,|0|$. $IA(e_i, r(|0|))$ is the set of IA interference links of e_i (active on c_j) in carrier-sensing range $r(|0|)$ that is the maximum carrier-sensing range of a channel.

3.2 Proposed Model Assumptions

In our proposed model we have considered the following assumptions.

– In our proposed model the transmission capacity of all frequency channels used equal .

– Each node is equipped with two or more radios for taking advantage of multiple-radio multi-channels technology.

– All the mesh nodes are static and all the paths in network are taken as single link paths.

– Only single flow at unit time is passing from each link (a links is not shared by multiple flows).

3.3 Decision Variable

Following is our binary decision variable that is used in our proposed channel assignment model. It states that if any directed link *ei* is activated on any frequency channel *cj* then it is equal to 1 and otherwise 0. Such kind of decision variable is also referred to as binary variable.

$$x(e_i, c_j) = \begin{cases} 1 & \textit{Directed link ei operates on channel } c_j \\ 0 & \textit{otherwise} \end{cases}$$

3.4 Constraint Set

In our proposed model constraints describe the unacceptable results. Following is the constraint set of our channel assignment model.

3.4.1 Single Channel per Link(SCL) Constraints: SCL ensures that every link in the set E (edges) of $G = (V, E)$ must be assigned only single frequency channel. This constraint shows that if e_i is a link and we sum this link over all frequency channels then it evaluates to 1.

$$\sum_{c_j \in K} x(e_i, c_j) = 1 \qquad \forall e_i \in E, c_j \in K \tag{1}$$

3.4.2 Coordinated Interference Constraints: Coordinated links are those links that do not create severe interference and network performance is not much affected if multiple coordinated links are assigned the same frequency channel. The channel capacity is in fact distributed amongst all the coordinated interfering links. Following constraint describes how a channel capacity is shared when multiple coordinated links are given same channel.

$$x(e_i, c_j) \,.\, \lambda(e_i) \,.\, f(e_i) + \sum_{e_k \in co(e_i)} x(e_k, c_j) \,.\, \lambda(e_k) \,.\, f(e_k) \leq Cc_j \qquad \forall e_i \in E, \forall c_j \in K \tag{2}$$

3.4.3 Information Interference (IA) Constraints: The channel assignment ensure that *IA* links do not operate on common channel. Here e_i and e_k are different links and they are assigned same channel c_j . So among *IA* intefering links only one of them will be active on channel c_j in the interference range $r\,|0|$.

$$x(e_i, c_j) + \frac{\sum_{ek \in IA(e_i, r|0|)} x(e_k, c_j)}{1 + \sum_{ek \in IA(e_i, r|0|)} (1)} \leq 1 \tag{3}$$

$$\forall e_i \in E, \forall c_j \in K, e_k \in E$$

3.4.4 Channel Per Node Constraint: Channel per link constraint insures that total number of frequency channels active on links of a particular node V_i should not be more than the number radios on that particular node.

$$\sum_{c_j \in K} \sum_{e_i \in I(v_i)} x(e_i, c_j) \leq n(v_i) \tag{4}$$

$$\forall e_i \in E, \forall c_j \in K \;\forall v_i \in V, c_j \in K, e_i \in E$$

3.5 Objective Function

The objective of our channel assignment model is to maximize the MRMC-WMN capacity. Getting the objective all the constraints must be taken into consideration. So we are adding all the link flows fulfilled over all the links and channels.

$$max \sum_{e_i \in E} \sum_{c_j \in K} x(e_i, c_j) \,.\, \lambda(e_i) \,.\, f(e_i)$$

$$s.t$$

$$\sum_{c_j \in K} x(e_i, c_j) = 1 \qquad \forall e_i \in E, c_j \in K$$

$$x(e_i, c_j) \,.\, \lambda(e_i) \,.\, f(e_i) + \sum_{e_k \in co(e_i)} x(e_k, c_j) \,.\, \lambda(e_k) \,.\, f(e_k) \leq Cc_j \qquad \forall e_i \in E, \forall c_j \in K$$

$$x(e_i, c_j) + \frac{\sum_{e_k \in IA(e_i, r|0|)} x(e_k, c_j)}{1 + \sum_{e_k \in IA(e_i, r|0|)} (1)} \leq 1$$

$$\forall e_i \in E, \forall c_j \in K, e_k \in E$$

$$\sum_{c_j \in K} \sum_{e_i \in I(v_i)} x(e_i, c_j) \leq n(v_i) \qquad \forall e_i \in E, \forall c_j \in K$$

4. Results and Discussion

In this section we discuss results taken from our proposed algebraic channel assignment model. For results ten different MRMC-WMN sparse and dense topologies are considered. Here sparse MRMC-WMN topology refers to a network topology where the mesh nodes are far from each other considering their physical distance. In such of kind of topologies the number of IA interfering links is large while in case of dense MRMC-WMN topology the mber of IA interfering links is low. In this paper first we compare model channel assignment results of both dense and sparse WMN topologies using AMPL solvers. To verify our model results further same kind of comparison has been made in OPNET simulator considering sparse and dense topologies. For simulation each mesh node is equipped with three radios. For data traffic generation that is our flow, Poisson traffic generator is used. In Table 1 all the parameters considered for simulation are given.

4.1 AMPL Results

In this paper we generate ten different MRMC-WMN topologies of sparse and dense WMN networks. Each WMN topology consists of 30 WMN nodes. Maximum Transmission range *Tr* of each node is 30 meter while carrier-sensing range *Cr* is 78 meters maximum that is 2.6 times of *Tr*. All the paths among mesh nodes are single link paths. For AMPL model all the coordinated and information asymmetry links have been generated through MATLAB. In this section AMPL results regarding channel assignment are presented. In Table 2 we show the average network capacities for both the sparse and dense WMN topologies taken for different flow demands (in packets per second). The source flow on each source node is varied from 50 to 500 packets/sec. Results in Table 2 is also represented by a line chart in Figure 4.

Parameter	Value
Radio Technology	IEEE 802.11b
Number of Nodes	30
Radios per Node	3
Transmission Capacity	11Mbps
Transmission Range	30 meter
Carrier-Sensing Range	2.60*30 meter
Number of Channels	3
Packet size	4096 bits
Terrain Area	270m X 270m
Transmission Power	0.1W
Packet Reception Power:	-50dB
Simulation Time	4 minutes

Table 1. Simulation Parameters

4.2 OPNET Results

For OPNET simulation we use the optimized channel assignment strategy given by our optimization model. The channel assignment strategy gives link-channel binding. All the parameters used during simulation are given in Table 1. Just like the AMPL results the flow demand is varied from 50 to 500 packets/sec. Total simulation time was 4 minutes for both sparse and dense networks. Table 3 presents average network capacities for both sparse and dense WMN topologies. These results are also represented in Figure 5. For each traffic load varying from 50 to 500 packets/sec we calculate percentage improvement of sparse over dense topology. Our proposed optimization model gives 8% capacity improvement of sparse over dense MRMC-WMNs.

5. Conclusion and Future Work

The network capacity of Multi-Radio Multi-Channel (MRMC)Wireless mesh networks (WMNs) is limited due to IA interference

Packets/sec	Sparse Network	Dense Network
	Average Capacity(packets/sec)	Average Capacity(packets/sec)
50	1395	1320
100	2210	1830
150	2290.5	1797.5
200	2425	1817.5
250	2590	1750
300	2700.5	1819.5
350	2715	1805
400	2870.5	1850
450	2910	1855
500	2968	1897

Table 2. AMPL: Network Capacity Comparison In Sparse And Dense WMN Topologies

Packets/sec	Sparse Network	Dense Network
	Average Capacity(packets/sec)	Average Capacity(packets/sec)
50	1397	1327.5
100	2392.03	2111
150	2758.63	2352.23
200	2994.7	2484.88
250	3392.45	2720.57
300	3458.63	2752.23
350	3697	2815.24
400	4006.63	2937.27
450	4020	3110
500	4092.45	3120.57

Table 3. OPNET: Network Capacity Comparison in Sparse and DenseWMN Topologies

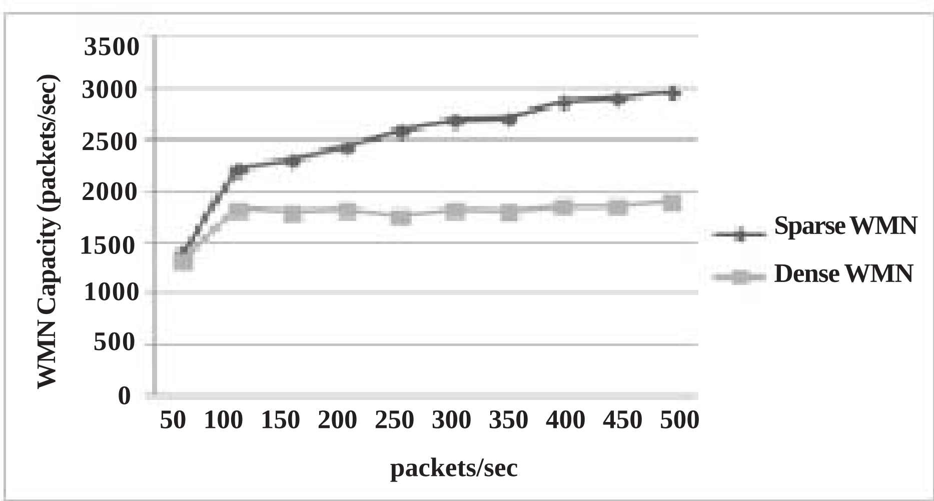

Figure 4. AMPL: Network Capacity improvement of sparse over desnse WMN

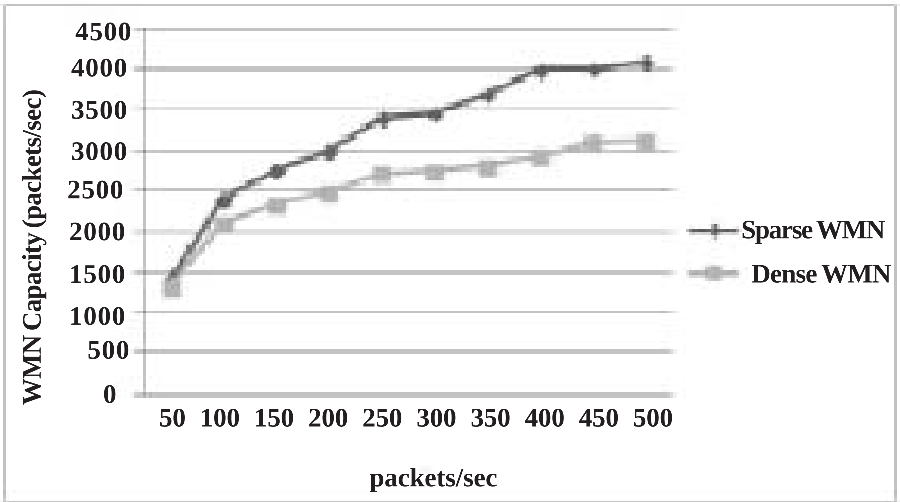

Figure 5. OPNET: Network Capacity improvement of sparse over dense

among channels. Various optimization models are proposed to perform the optimal channel assignment and minimize IA interference. In this paper we propose an optimization model that maximizes network capacity and minimizes IA interference in MRMCWMNs. The proposed optimization model gives better results for those environments where the information asymmetry (IA) interference is high. Simulation results show that proposed optimization model performs 8% better in sparse MRMC-WMN topologies. In future work we are looking forward to extend our proposed optimization model for both non-overlapping and partially overlapping channel assignment.

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