Channel Allocation Based K-Medoids in a Wireless Mesh Network

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Abstract. Wireless mesh networks (WMNs) are considered one of the most promising approaches to power networks using non-physical connection media that require high bandwidth and coverage. Because of its qualities in terms of bandwidth and coverage, they face quality of service problems such as throughput due in some cases to poor channel allocation. The channel allocation issue in a WMN is similar to a graph edge coloring problem which is an NP-complete problem. In order to solve this problem, various approaches have been proposed, some based on graph theory, some on conflict graph theory, and others using message exchange for synchronization on communication channel between nodes. In this paper, we present K-MEDAL, an approach to channel allocation in WMNs based on K-medoids algorithm. For our simulation, we used a testbed composed of 33 static nodes randomly arranged over an area of $1000Km^2$ in the NS-2 simulator. The K-medoids algorithm allowed us to build small network clusters to reduce the complexity of the channel allocation problem. Compared to other solutions found in the literature, the K-MEDAL approach shows out a 2 to 3 times increase in both the throughput distributed over the active links of a cluster and the aggregate throughput per cluster.

Keywords: Wireless mesh network · K-medoids · channel allocation · network cluster

1 Introduction

Recent advances in wireless technology have led to the emergence of a new class of network called Wireless mesh networks (WMNs). These networks aim to solve problems such as coverage area and quality of service in terms of bandwidth encountered by single access point networks. A WMN is similar to an ad-hoc

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network with the difference that the mobility of some network elements is limited or almost nil. It consists mainly of three types of nodes: mesh gateways (MG), mesh routers (MR) and mesh clients (MC). The function of MG is to allow interconnection of the mesh network with other networks. the MRs constitute the backbone of the network by allowing communications between different network clients. A MC is any terminal equipment that can connect to a MR in order to communicate with other clients. It should be noted that in a WMN, communications (requests and responses) are made by multi-hop through MR to MG. Figure (1) shows an architecture of a WMN.

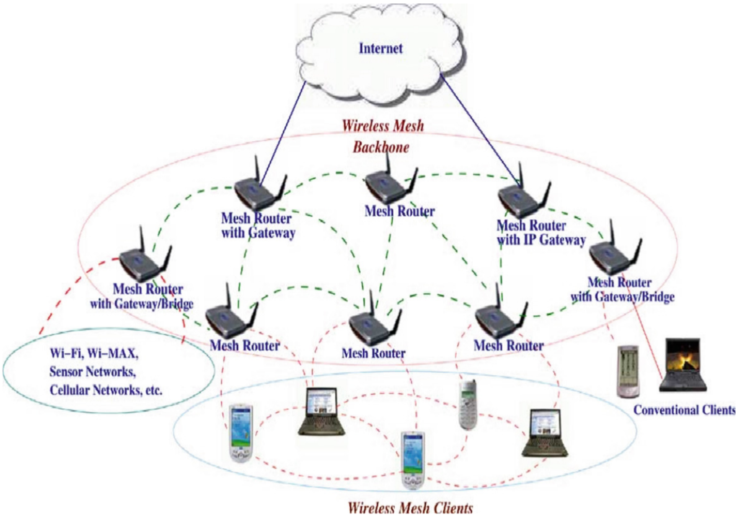


Fig. 1. Network architecture [1]

In a WMN, MRs are connected to each other by radio waves (channels) that are assigned to each router interface according to the number of interfaces. From this channels allocation between MR interfaces, can raise up interference problems which are disturbances (noise) that appear when a MR communicates with another. Interference can be internal when a MR interface interfere with each other or, external when it is produced by other neighboring MR. Since the number of channels used for communication is limited for a frequency, the challenge here will be to find a strategy that allows for interference minimization. Various approaches to solve the interference issue have been proposed in the literature. Some of them are based on graph theory using the solution of the graph edge coloring problem [4] or, conflict graphs [3]. Others are based on messages synchronization technique on the communication channel [5]. Unfortunately, these different solutions are not adapted to large networks with a large number of nodes and, are also not tolerant for certain network constraints, in particular the scalability control of a mesh network. Thus, the question that emerges is to find an approach that allows an efficient channel allocation that minimizes interference and adapts to the network's evolution.

In our paper,we propose K-MEDAL, a solution to the problem of channel allocation in a mesh network, based on k-medoids, an artificial learning method. It has the particularity of taking into account large networks made up of a large number of nodes. Indeed, these methods offer good properties to allow decision making based on static or evolving data. Artificial learning techniques are classified into three main categories which are: supervised learning in which the data passed to the learner is labeled; unsupervised learning in which the learner places the labels on the data himself and; reinforcement learning in which the learner observes his environment, makes decisions based on a maximum cumulative value. Specifically, we have used the K-medoids algorithm, an unsupervised learning technique, to contribute to channel allocation issue in a WMN. Our approach avoids considering the network as a whole. Instead, it focuses on the formation of sub-networks by constructing small network clusters and then applying channel allocation policies based on the interference between nodes in a cluster. To the best of our knowledge, this approach presents better results in terms of throughput, compared to the solution of [6] which uses the clustering principle according to the node's degree.

The rest of the paper is organized as follows: Section 2 presents related works on channel allocation in a WMN. Section 3 presents K-MEDAL, our K-medoids based approach. Section 4 presents the implementation and evaluation of our model. We conclude and propose future work in Sect. 5.

2 Related Worrk

Manos Delakis et al. [3] proposed a model for channel allocation in an experimental network deployed in the city of Heraklio. They used a model based on multipoint link conflict graphs to model internal interference. A multipoint link conflict graph (MPLCG) is a graph in which a vertex represents a set of interfaces that communicate with each other. From the MPLCG we can have a model that represents the internal interference in each node. This approach has the advantage of allowing internal interference modeling. However, the solution has some limitations in that it only works with directional antennas and, more importantly, the construction of the conflict graph is difficult when the number of nodes increases. Stefan Pollak et al. [4] in their work implemented a centralized two-phase algorithm for channel allocation in a WMN. First, a random channel allocation is made to nodes taking into account their expected loads and the interference effect of other links. Then, the algorithm tries to resolve the interference in the network using steps similar to the first. The difference here is that the channel assignment and routing paths are based on the results of the first phase. Note that the second phase only stops when a change is no longer needed. The advantage of this approach is that it allows channel allocation to take into account loads on links. in contrast, requires a large number of channels and a limited number of nodes. In their work Stefan Bouckaert et al. [5] present a simple but efficient channel selection scheme for dynamic mesh networks, based on the exchange of control messages. This scheme is able to perform channel configuration almost instantaneously, in a fully distributed manner and with minimal overhead. The Frequency Selection based on Message Exchange (FRESME) protocol is implemented with the IEEE 802.11b/g protocol for channel allocation. It is capable of rapid distributed channel selection in multi-channel and multi-interface mesh networks. The FRESME protocol is limited by the fact that the approach requires node synchronization, which incurs significant overhead on the network, and scaling is very complicated for networks with large nodes.

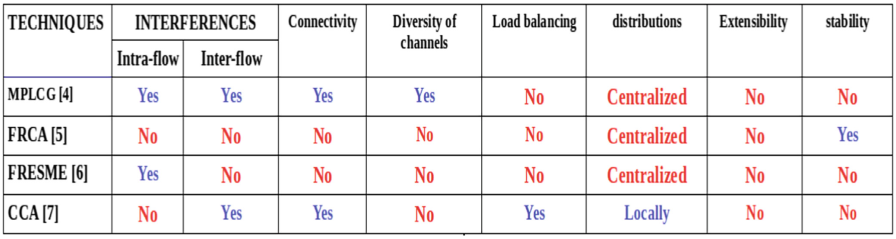
Sadeq Ali Makram et al. [6] worked on an allocation model in a mesh network based on the clustering approach by building small clusters of subnets. In their approach, instead of considering the network as a whole, they preferred to divide it into smaller clusters and manage the channel assignment locally in each cluster. The goal of clustering is to minimize the complexity of channel assignment into smaller, more manageable local problems. For cluster formation, they use the number of neighbors directly connected to a node and, depending on this value, the node will be elected the cluster head of nodes that are connected to it. This approach also allows reusing channels between clusters in order to minimize interference. It should be noted that the solution has some shortcomings: (1) the approach causes a lot of internal interference because only one channel is assigned to all nodes in a cluster; (2) the method used for cluster formation is not optimal because it can have multiple clusters, which can be difficult to manage.

After presenting these related works on channel allocation, we compare them according to the criteria that a good channel allocation algorithm proposed in [3] should fulfill.Indeed, the authors of [3] argue that a channel allocation algorithm must guarantee: (1) interference control and, (2) network scaling. Looking at Table 1, we can see that the solutions we just outlined do not meet these criteria both on interference control and network scalability. The table is filled with the following two values:

No: indicates that the proposed solution does not meet the criteria.

Yes: indicates that it does.

Table 1. Comparative table of different approaches



TECHNIQUES	INTERFERENCES		Connectivity	Diversity of channels	Load balancing	distributions	Extensibility	stability
	Intra-flow	Inter-flow						
MPLCG [4]	Yes	Yes	Yes	Yes	No	Centralized	No	No
FRCA [5]	No	No	No	No	No	Centralized	No	Yes
FRESME [6]	Yes	No	No	No	No	Centralized	No	No
CCA [7]	No	Yes	Yes	No	Yes	Locally	No	No

In this section, we have presented works dealing with the solution of the channel allocation problem in a mesh network. We highlighted the advantages that each of them proposes in a specific context for WMNs. We have also noticed some criteria that are not fulfilled by these approaches in terms of channel management, node management or network scalability. The main common limitation of these different approaches is the number of nodes used for their implementations, which do not support scaling.

3 Channel Allocation by K-Medoids

In this section, we propose K-MEDAL which consists of two main steps: the first one consists of forming clusters and, the second consists of making an allocation of channels to different network.

3.1 Constraints on Nodes

Our model must satisfy a number of conditions. We assume that wireless mesh routers have the following characteristics:

- Each mesh router has at least 3 interfaces.
- All mesh routers are fixed.
- The mesh routers are randomly distributed in the target area.
- Each mesh router has a fixed position along the x-axis and y-axis.
- Each mesh router can communicate with other nodes in the network.

3.2 Network Model

We used a graph to model the network. The WMN is a graph defined by $G = (V, C, E)$ with :

- $V = \{V_1, V_2, ..., V_n\}$ being the set of nodes;
- $C = \{C_1, C_2, ..., C_n\}$ being the set of available channels;
- $E = \{(v_i, u_j, c_r) | v_i, u_j \in V \wedge c_r \in c\}$ being the set of wireless links between nodes v_i and its neighbors u_j on channel c_r. [6].

3.3 Step 1 :Cluster Model

The allocation of channels requires a definition of a set of sub-networks from the formation of clusters such that $G = \{G_1, G_2, ..., G_K\}$ with :
$G_i = \{V_1, V_2, ..., V_n\}$ and **n** the number of nodes in the cluster G_i and **K** is the number of cluster. We apply the K-medoids algorithm to form the clusters. A node will be assigned to a cluster according to its position relative to the cluster head that is closest to it. Cluster heads are first randomly selected and then calculated. Clusters are formed with respect to the interference range of the centroids in each cluster. A node will belong to a cluster if that node is within the interference range of centroid. We specify that a wireless mesh router is characterized by two metrics which are: the transmission range and the interference range. The transmission range is the maximum distance a node can transmit,

while the interference range is the distance at which any node within that radius can disrupt the source node's communication.
We used the following phases for clusters formation. The K-medoids algorithm forms clusters based on the Euclidean distance between them and nodes of the interference range of the centroids of each cluster. The process consists of the following phases:

- **Phase 1: Initial grouping**
  In this phase of the algorithm, we define the number of clusters, We then perform a random selection of the centroids of clusters and subsequently each node is assigned to a cluster according to its distance from the nearest centroid.
- **Phase 2: Re-clustering and recalculation of centroids**
  Following the initialization phase of the centroids, we compute the centroids of each cluster. If a cluster **k** has **n** nodes then the centroid μ_k will be calculated as follows: the coordinate pair: (1) allows us to calculate the average of the coordinates of nodes in the cluster to find the new centroid and then the Eq. (2) allows a reallocation of nodes in clusters according to the new calculated centroids.

$$\boldsymbol{\mu_k = \left(\frac{1}{n} \sum_{i=1}^{n} V_i x \ , \ \frac{1}{n} \sum_{i=1}^{n} V_i y \right)} \tag{1}$$

$$\boldsymbol{V_i \ \in \ G_k \quad , \ if \ \forall j \ \ |V_i - \mu_k| = min_j \ |V_i - \mu_j| \ \ and \ V_i \ \ \in PI_{\mu_k}} \tag{2}$$

  PI_{μ_k}: : is the interference range of the centroid μ_k

- **Phase 3: Choice of the centroid**
  After cluster formation, the node with the coordinates calculated in phase 2 is selected. If no node has these required coordinates then a node with coordinates closest to those of the calculated centroid is searched for.

The pseudo-code of our clustering algorithm is given below. Note in this pseudo-code that the exit condition of the loop is that the computed centroids are the same for two consecutive iterations.

3.4 Step 2: Channel Allocation in and Between Clusters

After dividing the network into subnets, we proceed to the channel allocation phase for different nodes within and between clusters. The channel allocation comprises three phases. The phase 1 is the definition of channels for inter-cluster connections. The phase 2 is the division of the remaining channels by the number of defined clusters. In phase 3, the channel allocation is done within and between clusters.

```
Algorithm 1: Algorithm $K - MED - WMN$
Input: Let K be the number of clusters
Let $G = (V, E)$ be the WMN
Output: $G = \{G_1, G_2, ..., G_K\}$the set of clusters
begin
    1.Initial formation of $G_k$ by initialization of centroids
    while the centroids of step $n + 1$ are not the same as those of step $n$ do
        2.calculation of centroids and reformation of clusters.
        3.centroids calculation and cluster reformation.
        4.Choice of centroids .
    end
end
```

- **Phase 1: Selection of channels for inter-cluster connections**
  In this phase we define the number of channels that will be used for inter-cluster connections. We take all available channels **C** minus the channels that will be used for inter-cluster connections.

- **Phase 2: Distribution of channels in clusters**
  Having defined the number of channels that will be used for inter-cluster connections, we now need to allocate the remaining channels according to the number of clusters for intra-cluster connections. Equation (3) allows us to define the number of channels that will be used for inter-cluster connections. Assuming that the frequency band has some **C**, channels, and that we have defined the number of channels for inter-cluster connections $\boldsymbol{C_{inter\_cluster}}$ we divide the remainder of the subtraction $\boldsymbol{C - C_{inter\_cluster}}$ by the number of clusters to get the number of channels in each cluster.

  $$\boldsymbol{C_G = \frac{C - C_{inter\_cluster}}{K}} \tag{3}$$

  C_G :Number of channels for each cluster.
  C: Number of possible channels
  $\boldsymbol{C_{inter\_cluster}}$:Number of channels defined for inter-cluster
  K : The number of clusters.

- **Phase 3: Channel allocation within and between clusters**
  As we already have the number of channels allocated to each cluster and the number of channels for inter-cluster connections, we proceed with the allocation. In this allocation we ensure that a node has a different channel on each interface.

The pseudo code of our channel allocation algorithm is given below. The algorithm assigns channels to nodes according to the clusters that were formed by the K-MED-WMN algorithm.

Algorithm 2: *Algorithm* $K-MEDAL$

```
   Input: Let $G = \{G_1, G_2, ..., G_K\}$ be the set of clusters formed
   Let $C = \{C_1, C_2, ......, C_n\}$ be the set of available channels
   Output: Mesh network with efficient channel allocation
1  begin
2      for each Cluster $G_i$ do
3          while $G_i \neq \emptyset$ do
4              for each $l_i \in E$ from $G_i$ do
5                  $l_i = c_i \in C_{G_i}$
6                  if $V_i$ is a border node such that $V_i$ et $V_j$ are linked by $l_{ij}$ then
7                      $l_{ij} = c_j \in C_{inter\_cluster}$
8                  end
9              end
10         end
11     end
12 end
```

The operating principle of the k-MEDAL algorithm is as follows:

- At the level of line 5, each link of a cluster will be assigned one of the possible channels for its cluster.
- On line 6, if node V_i is a border node, i.e. it is between two clusters and is connected to the neighbouring cluster by node V_j via the link l_{ij} . Then the link V_j through link l_{ij}. Then the link l_{ij} will be assigned a channel defined as inter-cluster channel.

Figure (2) below shows an example of allocation model between two clusters (cluster 1 and cluster 2) for which two channels have been defined for inter-cluster connections and the rest of the channels are used for intra-cluster connections.

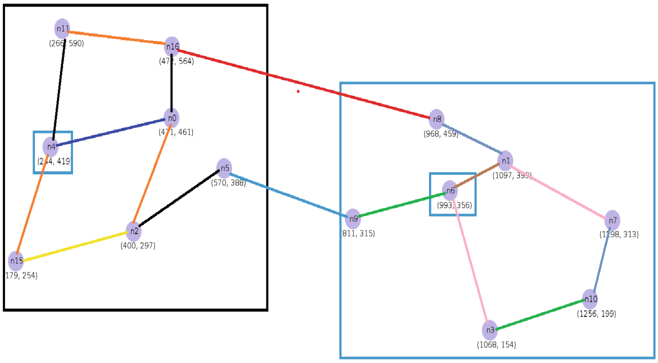


Fig. 2. Assigning channels to clusters in an WMN

In this section we described our k-MEDAL model for channel allocation, which supports networks composed of large numbers of nodes. It also aims at reducing interference in the network while ensuring good cluster formation. In the next section, we simulate and evaluate k-MEDAL.

4 Simulation and Results

We conducted our simulation in NS-2 with 33 static nodes randomly placed in a 1000 Km^2. The physical layers are configured to simulate the IEEE 802.11a standard, the simulation has a duration of 300 s. A Constant Bit Rate (CBR) traffic is attached to a connection with some important parameters such as the packet size and the time interval between two packets. The transmission rate of an exchange is 2.4 Mbps. The choice of the number of clusters was made by trial and error, to our humble knowledge there is no formal method to define this number. To do this we started with two, then three, then four clusters. We noticed that each time the number of clusters increased, the values of metrics were also better. Capturing with the NAM tool allows us to have on Fig. (3), an illustration of the k-MED-WMN algorithm presented in Sect. 3. On this Fig. (3) we have the formation of the following 04 clusters: cluster 1 of green color, cluster 2 of red color, cluster of yellow color and cluster 4 of black color.

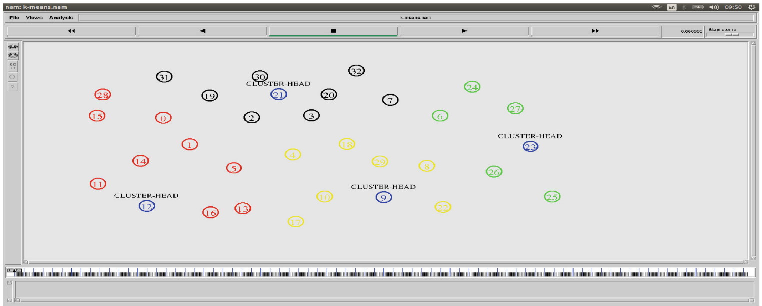


Fig. 3. Capture of the k-MED-WMN simulation (Color figure online)

We compared the experimental results of the K-MEDAL approach with those of the CCA approach [6]. Just to recall, CCA [6] also uses cluster construction to assign channels to nodes in a mesh network. The simulation scenario is based on the following two traffic models: (1) a single-hop traffic model and (2) a multi-hop traffic model.

4.1 Probability of Packet Loss

The probability of packet loss in our case here is defined by Eq.(4) [6] :

$$\boldsymbol{P \;=\; 1 - \left(\frac{r\left(l_{v}^{a},_{u}\ \ ,\ t\right)}{s\left(l_{v}^{a},_{u}\ \ ,\ t\right)}\right)} \tag{4}$$

On this equation(4) the loss probability is computed as follows: is computed $r\left(l^{a}_{v,u}, t\right)$ by a node (**u** or **v**) on the channel; **a** as a function of time over the number of packets sent $s\left(l^{a}_{v,u}, t\right)$ by a node (**u** or **v**); on the channel **a** as a function of time in each cluster. We can observe on Fig. (4) that the packet loss probability is similar in both approaches in cluster 1 and slightly higher in clusters 2 and 3 for K-MEDAL, this means that the K-MEDAL algorithm has a weakness on this point.

4.2 Distributed Throughput on Active Links in a Cluster

Distributed throughput on the active links in a cluster is the overall throughput that can be achieved on a connection between nodes when they are exchanged. The aim is to make a comparison on the distribution of the throughput on links of each cluster. To do this we proceeded as in the comparison of the packet loss probability, taking links in each cluster with the best results and comparing them with those of links of the K-MEDAL approach. It can be seen from Fig. 5 that the K-MEDAL approach shows much better results compared to the On-demand CCA approach.

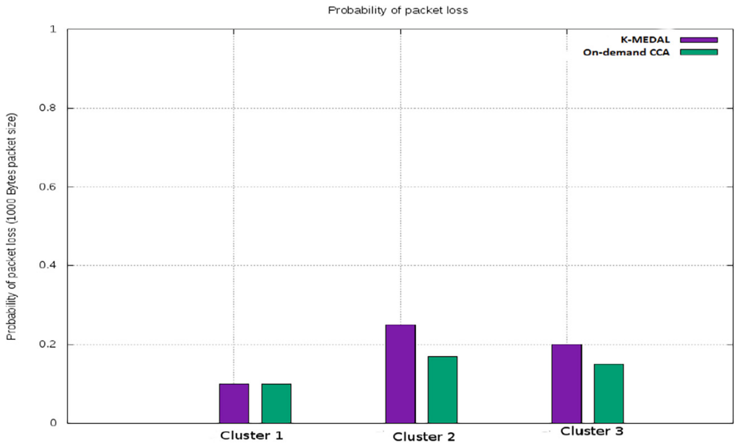


Fig. 4. Probability of packet loss

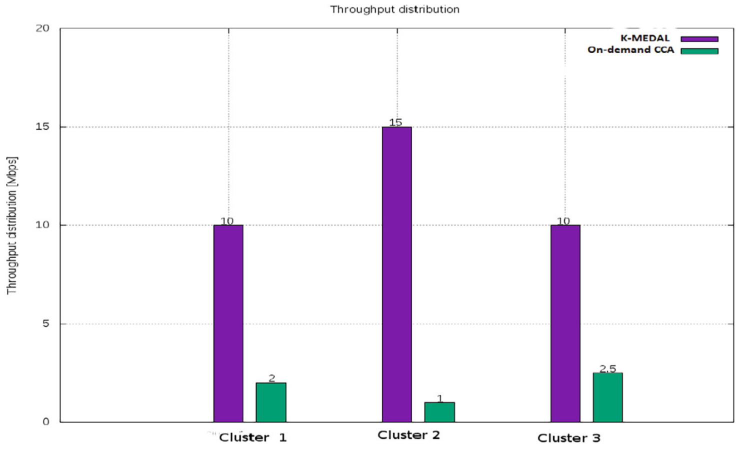


Fig. 5. Distributed throughput on active links in a cluster

4.3 Aggregate Throughput per Cluster

The aggregate throughput per cluster is the overall throughput that can be achieved in all clusters. The evaluation of the aggregate throughput of each cluster shows that the K-MEDAL approach has an aggregate throughput 2 to 3 times higher than the On-demand CCA approach. Figure 6 on a possible case simulated on the aggregate throughput confirms the advantage of the K-MEDAL approach compared to On-demand CCA.

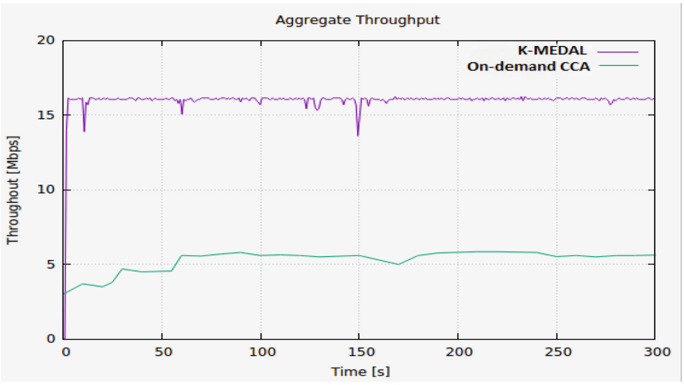
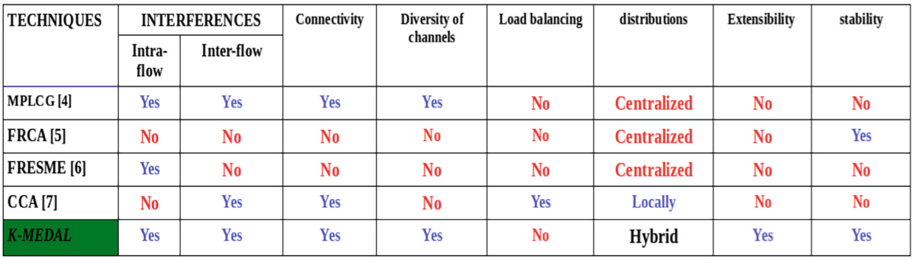


Fig. 6. Aggregate throughput per cluster

5 Discussion

After having implemented and tested our solution, we compare it according to the criteria mentioned in [3], to other existing approaches discussed in the Sect. 2. An overview is shown in Table 2. We see that the K-MEDAL approach fulfils several criteria of a good channel allocation algorithm compared to others.

Table 2. Comparison of the different existing approaches and the k-Medoids-al approach



TECHNIQUES	INTERFERENCES		Connectivity	Diversity of channels	Load balancing	distributions	Extensibility	stability
	Intra-flow	Inter-flow						
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FRCA [5]	No	No	No	No	No	Centralized	No	Yes
FRESME [6]	Yes	No	No	No	No	Centralized	No	No
CCA [7]	No	Yes	Yes	No	Yes	Locally	No	No
K-MEDAL	Yes	Yes	Yes	Yes	No	**Hybrid**	Yes	Yes

In WMNs, VoIP is one of the main applications for voice communication. In order to provide a good quality of service (QoS), the mesh network must have a good throughput distributed over the links and an aggregated throughput for the available bandwidth. This necessarily requires a good channel allocation. In our work, we have proposed a channel allocation model using the K-medoids method called K-MEDAL. From the implementation and evaluation, we found that the K-MEDAL approach improves metrics such as: distributed throughput over the active links in a cluster and, aggregate throughput per cluster. This is an important result for wireless communications, if we consider the application in a wireless community network. Despite some cases of packet loss observed in K-MEDAL, we believe that compared to others, our proposed model can provide good voice communication in a WMN.

6 Conclusion

The problem of channel allocation in WMNs has been receiving a lot of attention due to the need to satisfy a good quality of service. In this paper we have presented, implemented and evaluated K-MEDAL, an approach that allows channel allocation in a WMN, using the K-medoids algorithm for the division of the network into sub-networks or clusters. We have shown that this approach allows cluster formation by taking into account the position of nodes and their neighbors at the same time. Our experimental results showed that this method of channel allocation compared to other methods significantly reduces internal and external interference and improves the saturation and overall throughput in the network.

However, it should be noted that our approach has some limitations: (1) several continuous cluster formations are needed to have a good network configuration; (2) the number of clusters is done by trial and error; (3) the channel load balancing constraint according to the traffic in the network is not taken into account. Therefore, our future work will propose a model based on artificial learning algorithms to find the best possible cluster configuration for a candidate network. In particular, we will focus on the study of different clusters formations produced by K-MEDAL and will take into account the load balancing according to the traffic observed in the network.

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Availability of Data and Materials. No data or models were generated during the study. However, a code wrote in C and OTCL languages was used to implement the simulation.

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