A Method of Interference Co-processing in Software-Defined Mobile Radio Networks

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Abstract. The intensive network technology that is one of the key technologies of 5G is the main means to solve the explosive growth of data traffic demands in the future. However, with the implementation of network-inte-nsive deployments, serious interference problems are generated. The software-defined network (SDN) allows the separation of the control plane from forward plane, which provides the flexibility of dynamic network programming. Combining SDN with 5G is an effective method to copy with the interference management. This paper proposes an SDN-based mobile wireless network architecture to solve the problem of interference coordination in mobile wireless networks. Through the advantages of the SDN controller, the underlying wireless network topology information is centralized to the control layer that is running the optimization algorithm of resource allocation, which solves the problem of interference coordination. We introduces an Integer Programming to sovle the problem of formulation. A Tabu heuristic algorithm is used to solve the problem of interference coordination. The experimental results show that compared with the algorithm of non interference coordination, the proposed algorithm evidently reduces the interference value of the whole network.

Keywords: Mobile wireless network · Software defined networking 5G · Interference coordination

1 Introduction

With the rapid growth of mobile network services and user data traffic demands, the 5G has been proposed to satisfy the users' the variety of network QoS requirements and the flexible network Service-Level Agreement (SLA) [1]. In order to ensure low latency, high reliability and continuous wide-area coverage (providing 10 Gb/s user experience rate on the premise of guaranteeing user mobility and service continuity) for the 5G communication systems, the deployment of mobile wireless base station (BS) nodes will be more intensive, which results

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in a significant increase in the interference of wireless channel [2]. The Mobile Radio Interference (MRI) is an important factor in limiting the network coverage and data transmission in radio communication. In Mobile Wireless Networks (MWN), interference that produces low Signal-to-Interference-plus-Noise Ratio (SINR) seriously affects the efficiency of data transmission between the users, which brings about poor Channel Quality Identifier (CQI). The problem has been studied for decades, but it has been satisfactorily dealt so far. Therefore, MRI is an urgent problem to be solved. At the same time, network operators need to constantly update the system to cope with the explosive growth of new network services, mobile traffic and network application development, which ensure the user's demand for network services. However, the current network architecture and the control functions of assimilation can not meet the requirements of the 5G network services. In the meantime, the network control and management tools of modern telecommunication system should possess extensibility, flexibility and reconfiguration capabilities.

Software Defined Networking (SDN) [3] by the Open Networking Forum seem to be key technology enablers in the direction of meeting requirements such as greater flexiblity and new business models. The high level abstraction of network control and management from the underlying network equipments is actualized by the separation of the data planes and the control. A friendly and programmable northbound interface is defined in a software mechanism to centralize control of the underlying network equipments for achieving network traffic scheduling, which evidently improves the network programmability, flexibility and innovation. The mobile wireless network (MWN) combined with the SDN will augment flexibility, extensibility and automatic configuration ability [4,5]. This combination can be applied to wireless resource scheduling, mobile management and cooperative interference processing (CIP) required by the 5G mobile communication network. The interference minimization algorithm of single BS is constructed by [6], but it does't take into account the problem of multi BSs interference coordination based on MWN.

In this paper, with the problem of CIP in multi BSs and multiuser (MBSMU), we optimize the allocation of the wireless network resources (WNR), which achieve the lowest interference value in the whole MWN. The contribution of this paper is divided into three points. The contributions of this paper are as follows: Firstly, we define a set of MWN-related parameters (such as the transmission power, Modulation and Coding Scheme (MCS) and Resource Block (RB), etc.) that can be exposed to the SDN controller, then the algorithm runs by the SDN controller, which optimize the WNR to reduce the interference of the MWN and improve the efficiency of data transmission. Secondly, we construct an integer programming model for interference co-processing under multi BS and multiuser, which will be solved by the Tabu heuristic algorithm.

Our roadmap for the rest of the paper is as follows. We first describe the related work in Sect. 2. Section 3 we present the system design and architecture. The CIP's model is introduced on Sect. 4. In Section 5, we use Tabu to solve that problem. Section 6 contains results from comparing the performance of Tabu ICP and not Tabu ICP, and Sect. 7 summarizes the paper.

2 Related Work

In the traditional MWN, its resources management is performed in a distributed fashion [5], where each BS has its own decision on network resources. At the same time, 5G MWN will be composed of ultra dense deployments of BSs [7]. The researchers have already identified new issues that interference management has become highly complex. At present, some researches are devoted to combining SDN with MWN to solve that problem. SoftRAN [8] proposes that the BSs be abstracted as a virtual large base station (i.e., to be abstract as a logical centralized control plane), which can implement the abstraction representation of wireless resources (i.e., space, time and frequency slots). RadioVisor [9] proposes that the 3-dimensional wireless resources should be dynamically divided based on the traffic between virtual operators. The sliced radio resources take interference into account. But no a practical scheme is mentioned in the above paper to solve the radio resource control problem.

SoftMobile [10] is the SDN architecture for building heterogeneous mobile networks. In order to solve the interference management problem, the author constructs the development API of the programmable network to realize the combination of the SDN concept and the MWN. However, the papers do not provide specific resource allocation algorithms.

In the literature [11], the concept of a virtual cell (Vcell) is proposed, which is designed to overcome the lack of flexibility and scalability in traditional wireless networks. Representation by means of parameterization of mobile wireless resources such as time, frequency, space and power, the operator can design the resource scheduling algorithm in the controller to optimize the resource allocation. However, the resource allocation algorithm based on interference management has not been actualized.

The paper [6] studies the interference model in the wireless self-organizing network and proposes a graph-based interference model that is ingenious and easy to interfere with the construction of graphs. The authors use the resources of mobile wireless networks, such as transmission links, resource blocks and MCSs as the parameters that are used to calculate the weighted interference collision graph as the input of optimal algorithm scheduling. As the same time, the Integer programming method is put forward with the objective function of minimizing. However, in this paper, only the calculation of the minimum interference generated by all links under a single base station and multi-user is considered, and the calculation method of global interference is not considered in the case of MBSMU.

3 System Design

From the perspective of mobile wireless core network, SDN is viewed as a breakthrough in solving the problems of lack of scalability, inflexibility of deployment, and complex management in existing architectures. As shown in Fig. 1, the key element of the SDN MWN is the open interface between the control layer and

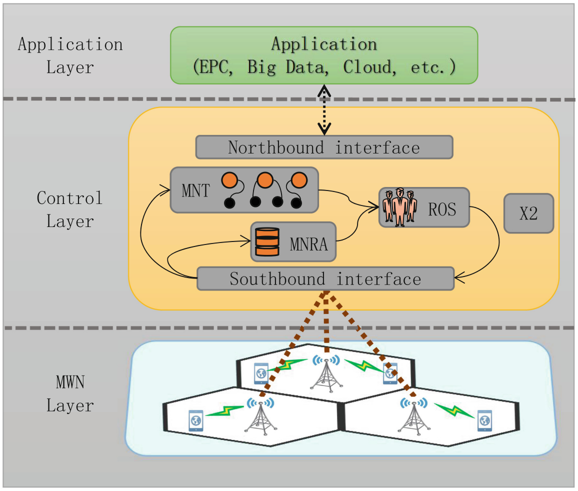

Fig. 1. Software-defined mobile radio access network architecture.

the data layer entity (BSs) and the programmability of the external application to the network entity (BSs). The main strategy of this architecture is the logical decoupling of the network from the software-based controller, which can implement network functions through the applications program that is to request and manipalate the services provided by the network. The architecture of this paper is designed as three layers: the MWN layer, the control layer and the application layer.

MWN Layer. In SDN mobile wireless networks, user devices (such as cellphones, self-driving cars) exchange data through radio with BSs. The wireless resources (such as RB, MCR and power) of the BSs will be reported to the controller through the southbound protocol to be aggregated and unified managed by the controller. When in the coverage of the BSs signal, the access of the user equipment will trigger the control information from the BSs to the control layer. Through a series of analysis and calculation, the controller feed back resources allocation policy to the BSs that finally completes the establishment of the data transmission channel with the user equipment.

Control Layer. The optimal allocation of wireless network resources under multi BSs multi-user environment is proposed in this paper to minimize the total interference in the global network. In order to achieve the above goal, the optimal allocation of mobile wireless network resources is achieved through three control modules such as MNRA (Mobile Network Resource Abstration), MNT (Mobile Network Topology) and ROS (Resource Optimization Scheduler). Firstly, the MNRA module is an abstract representation of the BSs resources reported from the Southbound interface, for example, the frequency, power and MCS usage of the BSs are parameterized as the input data of the optimization algorithm. This module ensures the optimization algorithm to make accurate decisions by updating data in real time. Secondly, MNT is a visual module for the underlying network topology. The module with SDN network topology module of the main difference is that MNT transforms quickly, with the movement of the user equipment, which directly affect the optimization algorithm, so the importance of this module is self-evident. Finally, the ROS module is the location of the optimization algorithm in this article. The input of ROS is provided by MNRA and MNT that obtains the transmission distance between BS nodes and user devices. Similarly, the usage of base station node resources is generated through MNRA. The tabu heuristic algorithm is proposed in this paper to solve the problem of optimal resource allocation. In 5G, the amount of user equipments is regionally increasing. In the architecture, to meet the problem of different number of equipment in different regions, we should realize the function of the cluster deployment draw on the traditional X2 interface of LTE. In the control layer, the X2 module can be used to realize the message communication between the control layer and the control layer.

Application Layer. The purpose of separating the application layer from the MWN is to realize flexible control of the network through the unified interface provided by the control layer. By introducing evolved packet core networks (EPCs) [12], cloud computing, big data and other technologies, the innovation of network can be improved. In the LTE architecture, EPCs is respectively composed of the mobility management entity (MME), serving gateway (SGW), and packet data network gateway (PGW).In our architecture, the MME system in the application layer implements the network topology management. When the user moves at a high speed, the MME system need to constantly update the topology. The SGW and PGW are used to implement route forwarding of data packets. The special function of the PGW is to allocate IP addresses, packet filtering and QoS services for the user equipment. The cloud computing and big data in the application layer can provide a deep analysis of the movement direction of user equipments, and the combine the entire mobile network BSs topology to pre-transmit data processing to avoid loss of data packets due to mobility of user equipment.

4 The Interference Coordination Problem

We use the three parameters of the resource blocks, MCSs and power in the MWN to select the transmission channel. We define the network parameters as follows:

$BSs\ M = \{M_1, ..., M_m, ..., M_M\}$,

users per BS $U = \{UE_1, ..., UE_u, ..., UE_U\}$,

$K = \{1, ..., k, ..., K\}$,

$MCSs\ R = \{1, ..., r, ..., R\}$.

In the optimal allocation of mobile wireless network resources discussed in [13], the wireless transmission path of the BS m to the user u can be allocated to the block of the R block, and the method of calculating the interference value produced by the MCS of the K is as follows:

$$\omega_{m,u}^{k,r} = \frac{P_{m,u}^{k} * \chi_{m,u}}{\rho_r} - \sigma^2 \tag{1}$$

The formulation $\chi_{m,u}$ represents the channel gain of base station m to user u. σ represents the noise density. $P_{m,u}^{k}$ represents the power value assigned by the base station when the m BS uses the k resource block to communicate with user u. With multiple BSs and multiple users, the problem of optimizing resource allocation for minimizing total interference in MWN can be translated into the following integer linear programming problem:

$$min \sum_{m=1}^{M} \sum_{u=1}^{U} \sum_{k=1}^{K} \sum_{r=1}^{R} \omega_{m,u}^{k,r} * \xi_{m,u}^{k,r} \tag{2}$$

subject to:

$$\sum_{u=1}^{U} \sum_{r=1}^{R} \xi_{m,u}^{k,r} \leq 1 \qquad \forall k \tag{3}$$

$$\sum_{r=1}^{R} \rho_{u,r} \leq 1 \qquad \forall u \tag{4}$$

$$\xi_{u}^{k,r} \leq \rho_{u,r} \qquad \forall u, k, r \tag{5}$$

$$\sum_{m=1}^{M} \xi_{m,u}^{k,r} = 1 \qquad \forall u \tag{6}$$

$$\sum_{k=1}^{K} \sum_{r=1}^{R} TP_{m,u}^{k,r} * \xi_{m,u}^{k,r} \geq TP_{m,u}^{req} \qquad \forall m, u \tag{7}$$

$$\rho_{u,r} \in \{0, 1\} \qquad \forall u, r \tag{8}$$

$$\xi_{m,u}^{k,r} \in \{0, 1\} \qquad \forall m, u, k, r \tag{9}$$

Equations (3)–(9) represent the constraint functions for the optimization problem expressed in (2) where the expression for $\omega_{m,u}^{k,r}$ is given in Eq. (1). In this case, $\xi_{m,u}^{k,r}$ (9) is a decision binary variable that is equal to 1 if user u of macrocells m uses MCS r in RB k, or 0 otherwise. Similarly, $\rho_{u,r}$ (8) is a decision binary variable that is equal to 1 if user u make use of MCS r, or 0 otherwise. Constraint (3) makes sure that RB k is only assigned to at most one user u, and Constraints (4) and (5) together guarantee that each user is allocated to at most one MCS. Constraint (7) make sure that each link achieves its throughput demands $TP_{m,u}^{req}$. Equation (6) represents that user u can only belong to base station m.

Algorithm 1 Tabu search algorithm

```
π := π_0, f_π := f(π_0)
π_best := π, f_best := f_π
T := φ
t := 0
push π_best into T
while t < time do
    t := t + 1
    π_best^neigh := NULL
    f_best^neigh := +∞
    for each π' ∈ N(π) do
        if π' ∉ T then
            f_π := f(π')
            if f_π' < f_best then
                π_best := π'; f_best := f_π'
                π_best^neigh := π'; f_best^neigh := f_π'
                break;
            end if
            if f_π' < f_best^neigh then
                π_best^neigh := π'; f_best^neigh := f_π'
            end if
        end if
    end for
    if f_best^neigh < f_best then
        π := π_best^neigh; π_best := π; f_best := f_best^neigh
    end if
    push π_best into T
    if T.size() > tabulength then
        remove first element from T
    end if
end while
```

5 Algorithm

In this section, we use a heuristic algorithm to solve the problem of resource allocation in MWN with the minimum system interference in the case of multi BSs and multi users. The Tabu search Algorithm 1 solves all the local optimal solutions by using the evaluation function (i.e., the function f in the algorithm), which is solved by sequential iteration with TIME of the Tabu step to procure the global optimal solution. At the same time, in order to avoid the search process falling into a dead circle, the solution is marked by the Tabu table T. The input of the algorithm is π_0 and the output of the operation is π_{best}. Initially, an initial solution π_0 is defined, and the initial value f_π is obtained by solving the definition f, and the T is empty at the same time. In the algorithm, we define π_{best}^{neigh} and f_{best}^{neigh} record the local optimal solution and its function value in the search process, so that we can easily filter the solution in circulation. In each cycle, the possibility of searching the optimal solution π is carried out in the domain of solution. When the length of the Tabu table is larger than that of the pre defined tabulength, the Tabu table needs to be cleaned to remove the preferences in the table.

6 Performance Evaluation

In this paper, the Tabu algorithm is written through JAVA program code. We use the GT-ITM tool to generate the MNT. The MNT is configured to have 15 to 55 users. To emphasize interference of the number of users, The number of BSs in our experiment is fixed to 5. We proposes three algorithms (i.e., Tabu algorithm for non-interference co-processing (Tabu not ICP), Tabu algorithm for interference co-processing (Tabu ICP), and non-Tabu algorithm for interference co-processing (ICP not Tabu)) to compare the results.

Figure 2 shows that as the number of users increases with the constant BSs, the interference value of the whole network increases significantly, which is sufficient to affect the normal communication of the user. Through the comparison of Tabu not ICP and Tabu ICP algorithm, we can conclude that the interference coordination algorithm greatly reduces the interference value of the whole network. At the same time, Through the ICP not Tabu algorithm and the Tabu ICP algorithm, the Tabu genetic algorithm can effectively reduce the interference value in the case of the same consideration of interference coordination.

In Fig. 3, we verify the power consumption of the algorithm in the whole network. It is obvious that the power consumption of the three algorithms is very close, which is because the basic power values need to be guaranteed that each user is able to send data successfully. The power nonlinearly increases with the increase of the number of users. Tabu ICP reduce the interference value in the prophase, which brings about the data can be sent with less power. However at the end, it is equal to the other two algorithms because the ICP involves several BSs working together, which results in the power consumption is doubled at this stage.

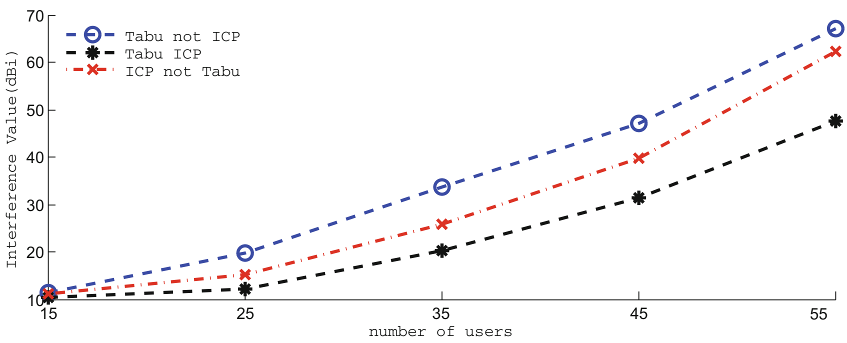

Fig. 2. Interference value

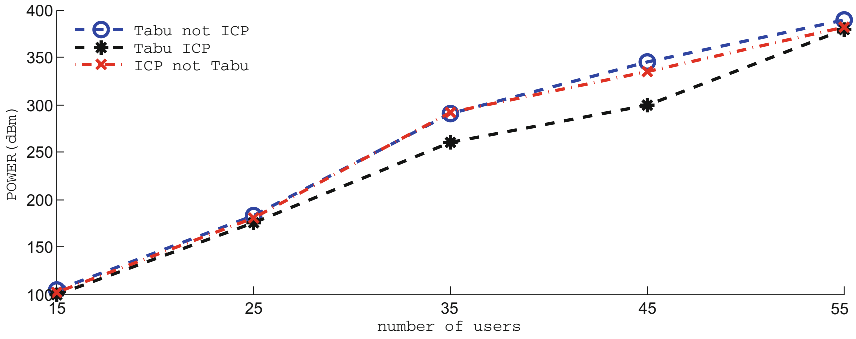

Fig. 3. Power usage

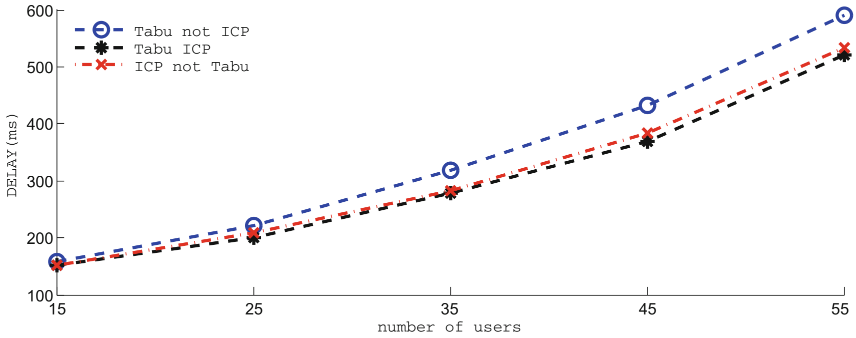

Fig. 4. Delay

The delay shown in Fig. 4 represents the time required for the algorithm to allocate the wireless resources to the user successfully. As we can see in the figure, compared to the other two algorithms, the delay of the algorithm Tabu not ICP is relatively large, which is mainly due to the utilization of the resources of the incomplete network. It only considers whether the resources can be allocated on a single BS. It will be waiting for adequate resources, which leads to the increase of time.

7 Conclusion

This paper mainly addresses the problem of resource allocation in MWN under multi-BSs and multi-users in order to minimize global network interference. With summarizing and expounding the current SDN wireless network, we propose a mobile wireless architecture based on SDN that is applicable to this paper. The three modules (MNRA, MNT and ROS) contained in the control layer are used as the modules of the input and loading algorithm to solve interfence coordination problem. In order to solve the above resource allocation problem, an integer programming model is proposed, which is solved by Tabu heuristic algorithm. The experimental results show that compared with the non-interference coordination algorithm, the proposed algorithm greatly reduces the interference value of the whole network.

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