

Self-Organizing Scheme Based on NFV and SDN Architecture for Future Heterogeneous Networks

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Abstract Future cellular networks will be of high capacity and heterogeneity. The structure and architecture will require high efficiency and scalability in network operation and management. In this paper, we address main requirements and challenges of future cellular networks and introduce network function virtualisation (NFV) with software defined networking (SDN) to realize the self-organizing (SO) scheme. NFV integrates the hardware appliances together in industry standard servers. And SDN performs as core controller of the network. The proposed SO scheme is based on soft fractional frequency reuse (SFFR) framework. The scheme takes different traffic demands into consideration and allocates the power adaptively. Finally the system is proved to be more scalable, energy-saving, and intelligent.

Keywords SO · NFV · SDN · SFFR

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1 Introduction

Cellular networks are evolving rapidly in recent years. In 2008, LTE was first proposed and then LTE-A [1] was developed in 2010 [2]. By 2020, the fifth generation (5G) of the wireless network is scheduled to be marketed [3].

In future cellular networks [4], the capacity and traffic demand of the network will increase constantly. The network will carry massive and increasing number of services and devices to enhance the system capacity and scalability [5].

Toward the huge scale and compatibility of the network, users will access with various categories of terminals [6]. Consequentially, heterogeneity will emerge as a feature character of the network [7]. And cells with diverse sizes [8] will be applied in the system. Multiple options will be offered by the network and diverse terminals with different capabilities will be accessed [11]. Energy and spectrum cost will become shortage when supporting such scale of the system. One solution to solve the problem is to control the use of frequencies over different channels in the network, such as fractional frequency reuse (FFR) scheme.

FFR divides the whole available resources into two groups, namely, the major group and the minor group, serving cell-edge users and cell-center users, respectively. There have been also other variations derived from FFR proposed for macro-cell networks, e.g., partial frequency reuse (PFR) and soft frequency reuse (SFR) [9, 10]. In PFR scheme, a common frequency band is used in all sectors with equal power, while the power allocation of the remaining sub-bands is coordinated among the neighboring cells in order to create one sub-band with a low inter-cell interference level in each sector. In SFR schemes, each sector transmits in the whole frequency band. However, the sector uses full power

in some frequency sub-bands while reduced power is used in the rest of the frequency band.

Moreover, the application of HetNets also increases the operating expense (OPEX) of the system. The requirements of users, network providers and operators need to be agreed in a cost-effective way. Adaptivity and intelligence are strongly required to effectively manage the heterogeneous network (HetNet) [12]. Therefore, numerous algorithms have been proposed to enhance the intelligence of the system. Software-defined networking (SDN) [13] with pre-defined self-organizing (SO) [14] scheme is motivated to combine intelligence and autonomous adaptivity into future cellular networks.

In natural systems, certain biological population exhibit unique organised behaviour autonomously to achieve specific status, such as a group of birds, fish, sheep, insects and so on [15]. The idea of SO comes from such natural examples, and is applied in biology, computer science and cybernetics [16]. And it has improved the system a lot since its application in cellular networks.

The rapid update of algorithms and technologies promotes upgrade of hardware appliances. Large amount of hardware-based appliances would be updated or replaced [17]. In the future, the renewal of technologies will be even faster. If the system is highly hardware-relied, the system will be costly in updating the existing equipments for applying new technologies [18]. Intelligently managing the devices and resource in the network is one of the key challenges [19]. So it is necessary to apply network function virtualization (NFV) [20] and SDN [21] architecture to reduce the cost of system upgrading.

Our work focuses on the requirements of future cellular networks and an architecture is proposed to achieve a self-organizing network with combining NFV and SDN. The proposed SO scheme aims at improving the efficiency, reducing the cost of the infrastructure and implementing remote and intelligent control of the system.

The paper is organized as follows: In Section 1, we present the motivation of for this work. Then in Section 2, we propose the architecture of improved mechanism and relative analysis. Our SO scheme is described in Section 3. Simulation results are analyzed in Section 4 to confirm the performance of our proposed scheme. Finally the Section 5, we give a conclusion for our work and address future challenges.

2 System model

As Fig. 1 shows, the system includes the following components: service provider, remote management / control, NFV and SDN architecture and the self organizing cellular network. Service provider provides services that the system

requests. Remote management / control is enabled by NFV and SDN to increase the flexibility of the network. We apply SO scheme on NFV and SDN architecture and provide an optimized management of the network.

2.1 NFV and SDN architecture

Network function is usually built within an infrastructure with pre-defined interfaces and functional behaviours. NFV implements network functions by using servers and storage devices of industry standard, which sometimes also deployed as virtual machines. By reducing the number of hardware appliances and sharing high volume hardware, NFV contributes efficiency, flexibility of the system.

SDN maintains the network state and the resource allocation, centralizes the network controller and influences the whole system. Also, algorithms can be applied flexibly and bring intelligence to the system. Thus, SDN produces the computing results for an optimized network status. Moreover, new ideas are much easier to be introduced to the network through software instead of hardware appliances.

As shown in Fig. 2, NFV and SDN are highly complementary on concept and can be combined to achieve greater efficiency. The expensive and fixed appliances are replaced by high volume hardware and progressive software.

In NFV infrastructure, hardware is shared by applying high volume industry standard servers, storage and switchers. High volume servers holds multiple Virtual Machines (VMs), on which run multiple Network Functions (NFs). The high volume infrastructure are located in data centres that is much advanced in managing and controlling.

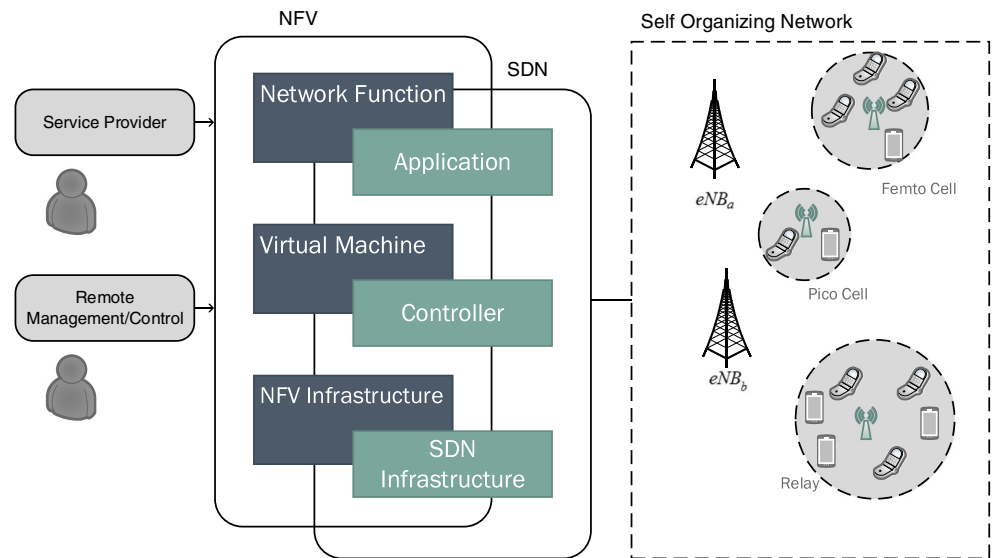
SDN is supported by NFV hardware. It is composed by application, controller and infrastructure. SDN application is software implementation of NFs. Controller is connected with application by Northbound API (e.g. FML, ProCera, Frenetic, RESTful) and connected with infrastructure by Southbound API (e.g. OpenFlow, ForCEs, PCEP, NetConf, IRS). SDN infrastructure includes hardware such as router, switcher, Access Point (AP) and so on.

2.2 Self-organizing multi-layer FFR model

Proposed SO scheme realizes a green downlink power control scheme oriented by traffic demand. The goal is to make power allocation accommodate different traffic load scenarios and thus improve users' experience and energy efficiency. Our conception is drastically different from the static schemes that configure parameters according to full traffic load scenarios only.

SFFR scheme has been proposed to improve the overall cell throughput of fractional frequency reuse (FFR) [9].

Fig. 1 System model of the proposed scheme



Partial frequency reuse (PFR) does not make use of the sub-bands allocated to the outer region in the adjacent cells, whereas the SFFR scheme utilizes these sub-bands for the inner UEs, but with low power levels.

In [10], the authors studied downlink transmit power allocation in soft FFR under two different coordination cases, i.e., loosely and tightly coordinated cells. In loosely coordinated cells, the sub-band transmit powers are allocated so that the cell edge user meets the required throughput. This way, the loss of average cell throughput can be reduced by appropriately configuring the number of sub-bands for

inner and outer regions. On the contrary, in tightly coordinated cells, sub-band power allocation can change packet by packet in each scheduling period. In this case, the loss of spectral efficiency can be minimized regardless of the number of sub-bands due to its fast coordination. Clearly, both loosely and tightly coordinated cells have ignored the effect of traffic demand.

It is worth noting that our proposed scheme is initiated from soft fractional frequency reuse (SFFR), an enhanced SFR scheme, but is not limited to that. We assume the cell can be divided into more than two layers and for each layer the power can be allocated abiding by corresponding traffic demand. We further impose a threshold of maximum power to each layer, in order to retain the fundamental inter-cell interference cancellation (ICIC) function of a frequency reuse scheme.

In [16], the authors proposed an improved multi-layer cell structure to make full use of the sensed spectrum information and achieve flexibility. It is an open problem that the edge users of a cell are always having to face stronger interference. As aforementioned, there already exist some static interference coordinating schemes, such as SFR, PFR and SFFR, which divide the cell into exterior and interior regions with different frequency and power.

In a smart low power node (LPN), however, the concept of exterior and interior can be further extended to a multi-layer structure. There might be more than 2 layers in the system, where we also impose a power upper bound P_{lim} in case of a overlarge power demand that may cause strong interference to neighboring cells. In this paper, we will integrate dynamic traffic demand into the self-organizing multi-layer FFR model, and thus form a green approach to achieve better performance in downlink transmission.

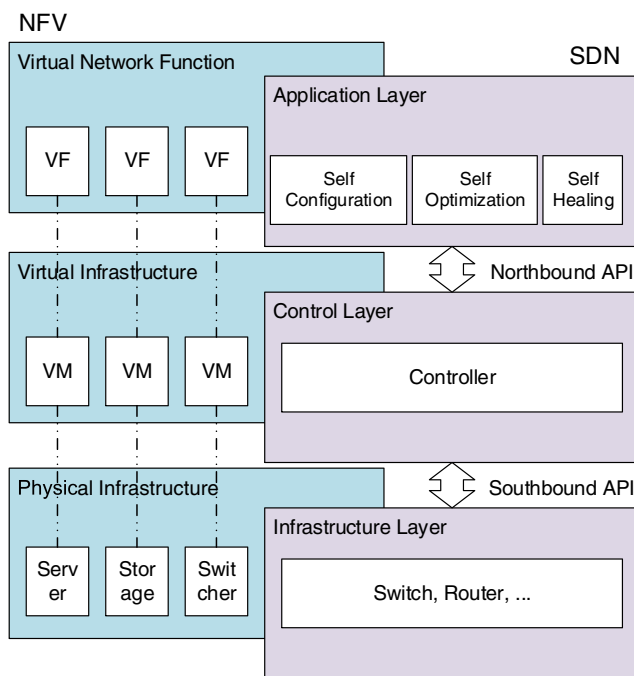


Fig. 2 NFV and SDN architecture

3 Proposed self-organizing scheme

In future cellular networks, heterogeneous wireless environment of the user equipment is dynamic in time and space domain. Manual operation is insufficient and may cause delay and possible errors. Therefore, the network needs to have self-organization function to make the wireless environment more adaptive and effective [13].

In this solution, SO scheme acts as the equipment of NFV virtual function and SDN operation. When the system is abnormal, NFV and SDN architecture can realize remote control and handling to deal with it.

3.1 Configuration of traffic demand

Where r_k denotes the traffic demand of user k in the service area, F denotes the total bandwidth and N denotes the total number of users. Then for the whole service area, the obtained traffic for user k is given by

$$B_k \log_2(1 + SINR_k) \tag{1}$$

So $SINR_k$ is given by

$$SINR_k = \frac{p_{i,j} PL_{i,j,k}}{\sum_{i',j'} p_{i',j'} PL_{i',j',k} + n_0 B_k} \tag{2}$$

Where $B_k = \frac{F}{N}$, $p_{i,j}$ denotes the power spectral density of the j th BS in the i th sector. $j = 0$ denotes the macrocell BS. However, $j = 1$ denotes the LPN BSs in this sector. $PL_{i,j,k}$ is the path loss of user k from the j th BS in the i th sector.

3.2 Power allocation on traffic demand oriented SFFR

As an enhanced SFR scheme, SFFR is gaining more and more recognition. However, as with other static methods, its poor adaptability to meet the demand of dynamic change of each sector. Based on the above reasons, we consider the different cell SFFR traffic demand and presents the flow demand oriented, rather than the pursuit of the overall increase in throughput scheme. Due to the outstanding adaptability of our scheme, our scheme shows significant advantages in energy saving.

$$\begin{aligned} \min & \quad F_c p_{i,0}^c + F_e p_{i,0}^e \\ \text{st.} & \quad B_k \log_2(1 + SINR_k) \geq r_k \\ \text{for} & \quad \text{keccenter,} \\ & \quad SINR_k = \frac{p_{i,0}^c PL_{i,0,k}}{\sum_{i',0} p_{i',0}^c PL_{i',0,k} + n_0 B} \end{aligned} \tag{3}$$

$$\begin{aligned} \text{for} & \quad \text{keedge,} \\ & \quad SINR_k = \frac{p_{i,0}^e PL_{i,0,k}}{\sum_{i',0} p_{i',0}^e PL_{i',0,k} + \sum_{i',0} p_{i',0}^c PL_{i',0,k} + n_0 B} \end{aligned} \tag{4}$$

$F_c, p_{i,0}^c$ denotes the center region bandwidth and power spectral density, $F_e, p_{i,0}^e$ is for the edge.

3.3 Traffic based power allocation in multi-layer scheme

The traffic power allocation scheme mainly regulates SFFR flow interference coordination problem in Macro base station based on multi-layer HetNets. Next we will extend the traffic oriented power allocation to the LPNs in HetNets. In particular, we consider the multi-layer LPNs with cognitive radio capabilities of [7]. We mainly consider the power allocation in the LPNs of multi-layer to evenly distribute the traffic demand as a simple example.

Where the LPN was separated into m layers, $m \in \{1, 2, \dots, M\}$. p_m denotes the power spectral density of layer m . The power allocated to layer m is determined by

$$\begin{aligned} \min & \quad p_m \\ \text{st.} & \quad B_k \log_2(1 + SINR_k) \geq r_k \\ & \quad SINR_k = \frac{p_m PL_{i,j,k}}{\sum_A p_e PL_{i'',0,k} + \sum_B p_c PL_{i'',0,k} + \sum_C p_{i'',j'} PL_{i'',j',k}} \end{aligned} \tag{5}$$

where A denotes the macro BSs in which the Co-channel interfering edge users locate B is the macro BSs in which the Co-channel interfering center users locate C is the BSs in which the Co-channel with m locate.

3.4 Traffic demands acquirements

This part analyses the acquirements of traffic demands of spherical and exponential distribution. Here we assume the distribution of traffic demands ideally conforms to the distribution model and ignore the influence of the discreteness of users distribution.

3.4.1 Spherically distributed traffic demands

If the traffic demands are spherically distributed, then

$$\begin{aligned} t(r, \theta) &= \frac{3T_{total} \sqrt{R^2 - r^2}}{2\pi (R^2 - r_0^2)^{\frac{3}{2}}} \\ g(r) &= \int_0^{2\pi} t(r, \theta) r d\theta = \frac{3T_{total} r \sqrt{R^2 - r^2}}{(R^2 - r_0^2)^{\frac{3}{2}}} \end{aligned} \tag{6}$$

where $t(r, \theta)$ represents the traffic demand of a spot in the service area in terms of polar coordinates r and θ , and $g(r)$ represents the traffic demand along radius distribution.

Similarly, the total traffic demands for layer k is given by

$$T_{dk} = \int_{r_{k-1}}^{r_k} g(r) dr = \int_{r_{k-1}}^{r_k} \frac{T_{dtotal} r \sqrt{R^2 - r^2}}{(R^2 - r_0^2)^{\frac{3}{2}}} dr$$

$$= \frac{T_{dtotal} \left((R^2 - r_k^2)^{\frac{3}{2}} - (R^2 - r_{k-1}^2)^{\frac{3}{2}} \right)}{(R^2 - r_0^2)^{\frac{3}{2}}}. \tag{7}$$

Due to the concavity of $2^C \sqrt{R^2 - r^2}$, by integrating (12) to (9) we get another expression with appropriate condition relaxation,

$$p_k \geq r^\alpha (i_k + N_0) (C_{1k}r + C_{2k})$$

$$\geq r^\alpha (i_k + N_0) \left(2^C \sqrt{R^2 - r^2} - 1 \right), r_{k-1} \leq r \leq r_k, \tag{8}$$

where

$$C = \frac{3T_{total} (r_k^2 - r_{k-1}^2)}{2\pi F_k (R^2 - r_0^2)^{\frac{3}{2}}},$$

$$C_{1k} = 2^C \sqrt{R^2 - \left(\frac{r_k+r_{k-1}}{2}\right)^2} - \frac{C \left(\frac{r_k+r_{k-1}}{2}\right) \ln 2}{\sqrt{R^2 - \left(\frac{r_k+r_{k-1}}{2}\right)^2}},$$

$$C_{2k} = 2^C \sqrt{R^2 - r_k^2} \left(1 + \frac{C \left(\frac{r_k+r_{k-1}}{2}\right)^2 \ln 2}{\sqrt{R^2 - \left(\frac{r_k+r_{k-1}}{2}\right)^2}} \right) - 1. \tag{9}$$

Assume $p_k(r) = r^\alpha (i_k + N_0) (C_{1k}r + C_{2k})$, according to the solution to $p_k'(r) = 0$, we then can deduce the unique solution $r^* = \frac{-2C_{2k}}{3C_{1k}}$ and the related p_k .

$$p_k = \begin{cases} \max(p_k(r_{k-1}), p_k(r_k)), & r^* \notin [r_{k-1}, r_k] \\ p_k(r^*), & r^* \in [r_{k-1}, r_k]. \end{cases} \tag{10}$$

3.4.2 Exponentially distributed traffic demands

If the traffic demands are exponentially distributed, then

$$t(r, \theta) = \frac{T_{total} e^{-\frac{r}{r_0}}}{2\pi \left(2e^{-1} - \left(\frac{r_0}{R} + 1\right) e^{-\frac{R}{r_0}} \right) r_0^2}$$

$$g(r) = \int_0^{2\pi} t(r, \theta) r d\theta$$

$$= \frac{T_{total} r e^{-\frac{r}{r_0}}}{\left(2e^{-1} - \left(\frac{r_0}{R} + 1\right) e^{-\frac{R}{r_0}} \right) r_0^2} \tag{11}$$

The total traffic demands for layer k is given by

$$T_{dk} = \int_{r_{k-1}}^{r_k} g(r) dr = \int_{r_{k-1}}^{r_k} \frac{T_{dtotal} e^{-\frac{r}{r_0}}}{\left(2e^{-1} - \left(\frac{r_0}{R} + 1\right) e^{-\frac{R}{r_0}} \right) r_0^2} dr$$

$$= \frac{T_{dtotal} \left((r_0 r_{k-1} + r_0^2) e^{-\frac{r_{k-1}}{r_0}} - (r_0 r_k + r_0^2) e^{-\frac{r_k}{r_0}} \right)}{\left(2e^{-1} - \left(\frac{r_0}{R} + 1\right) e^{-\frac{R}{r_0}} \right) r_0^2} \tag{12}$$

Considering the convexity of $2De^{-\frac{r}{r_0}}$, the optimum p_k is given by

$$p_k \geq r^\alpha (i + N_0) (D_{1k}r + D_{2k})$$

$$\geq r^\alpha (i + N_0) \left(2De^{-\frac{r}{r_0}} - 1 \right), r_{k-1} \leq r \leq r_k, \tag{13}$$

where

$$D = \frac{T_{total} (r_k^2 - r_{k-1}^2)}{2\pi F_k \left(2e^{-1} - \left(\frac{r_0}{R} + 1\right) e^{-\frac{R}{r_0}} \right) r_0^2},$$

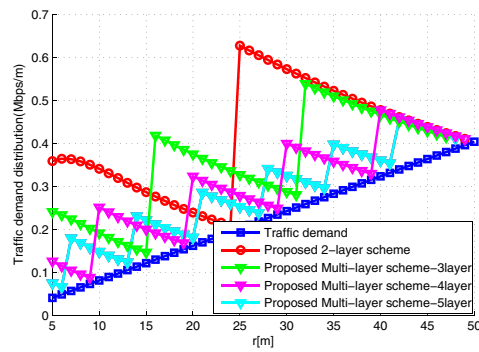
$$D_{1k} = \frac{2De^{-\frac{r_k}{r_0}} - 2De^{-\frac{r_{k-1}}{r_0}}}{r_k - r_{k-1}},$$

$$D_{2k} = \frac{r_k 2De^{-\frac{r_k}{r_0}} - r_{k-1} 2De^{-\frac{r_{k-1}}{r_0}}}{r_k - r_{k-1}}. \tag{14}$$

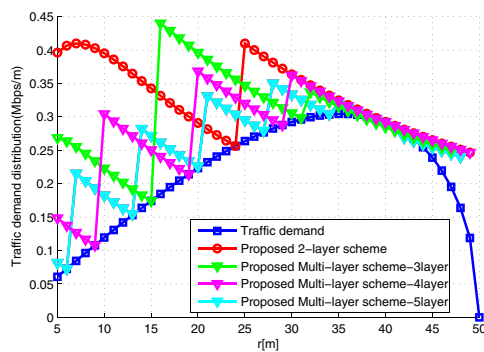
From equation (11), the solution to $p_k'(r) = 0$ is $r^* = \frac{-2D_{2k}}{3D_{1k}}$, which can then work with equation (8) to acquire appropriate p_k .

Table 1 Simulation setup

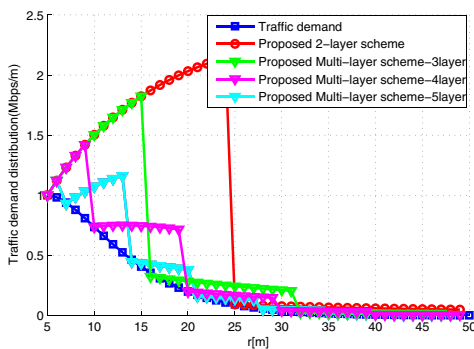
Cellular layout	Hexagonal grid, 19 cell sites, 3 sectors per site
Inter-site distance	500m
System bandwidth	1GHz
Simulation scenario	ITU-UMa
Antenna pattern(horizontal)	$A(\theta) = -\min \left[12 \frac{\theta}{\theta_{3dB}}, A_m \right]$, $\theta_{3dB} = 70degrees$, $A_m = 20dB$
Antenna configuration	Single-Input-Single-Output
eNB antenna gain	14dBi
Frequency reuse for eNB	SFFR Traffic aware based
Traffic model	Full buffer
Thermal noise density	-174dBm/Hz
Downlink interference	Explicit modeling (all links are simulated)
Scheduling strategy	RR



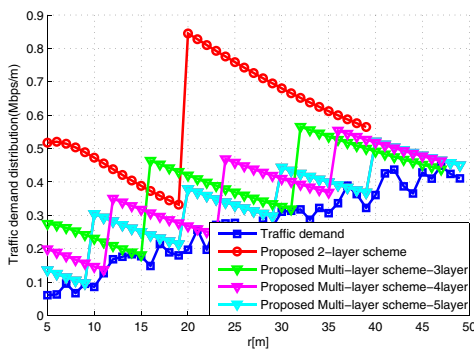
(a) Uniformly distribution



(b) Spherical distribution



(c) Exponential distribution



(d) Random distribution

Fig. 3 Traffic demand and the resulting actual obtained traffic concerning random distribution with changed cell range

4 Simulation results and performance analyses

The aforementioned part of the content is about the uniformly distributed traffic demands we proposed. The main parameters in Table 1 we use concerning the performance of the proposed traffic demand oriented SFFR in homogeneous networks.

Figure 3 compares the four different user distribution, namely uniform distribution, spherical distribution, random distribution and exponential distribution. From the chart we can clearly see that all of these can obtain more performance by increasing layer. Meanwhile, the increasing number of layers will cause more complexity, therefore we need a balanced consideration.

And the proposed system shows advantages especially on the following aspects.

SO strategy is very suitable to the dynamic cellular HetNet system. Compared with normal SO networks, our proposed SO strategy is programmable on SDN, which makes the system quite flexible and adaptable.

Due to the limited resource in mobile cellular system, it is required that the system is of high efficiency. The system becomes more efficient in dealing with nonlinear complex problem using optimization algorithm. And it is quite cost effective using NFV and SDN architecture because the update of the system is highly software-oriented.

5 Conclusion

There are limited resources of mobile cellular network, thus making the system with high efficiency is becoming especially important. In proposed solution, we use optimization algorithm make the system becomes more efficient in dealing with nonlinear complex problem. Due to the update of highly software-oriented system, it is quite cost effective using NFV and SDN architecture. It is proved that the proposed scheme is beneficial helps the system to be more scalable, flexible and intelligent.

The future work will concern about developing a distributed system to realize the scheme more effectively. And the trend of NFV and SDN will also be our critical focus area.

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