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OPTIMAL CONTROL OF MULTICAST VIDEO STREAMING IN 5G ULTRA-DENSE NETWORKS

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PH.D THESIS SUMMARY

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INTRODUCTION

1. Motivation

In the automation and control industry, ubiquitous devices and control system components are easily connected thanks to the development of disruptive wireless networking technologies. In the networked control system (NCS), recently studies on inreasing the flexibility, the ease of diagnose, and the system maintain capacity based on wireless connections have drawn significant attention from the control and automation community. Two main research trends: 1) control of networks to provide the service quality of communication networks for NCS to achieve optimal performance and 2) control over networks to come up with appropriate control strategies to reduce the impact of network constraints (bandwidth, congestion, ...) on control performance.

Recently, the mobile network explosion and the Internet development have played an important role in the realization of the Industrial Revolution 4.0 towards the Internet of Things (IoT) in various areas all over the world. It is estimated that by 2023 there will be about 5.3 billion mobile users (MUs) connected to the Internet to exchange data, especially video (accounting for 79%). This in turn requires not only the core network upgrades in a costly deployment but also the emerging wireless architectures, system models, techniques, and optimization designs in a much more cost-effective manner, so as to meet the upcoming surge of MUs' demand. In this context, the 5th generation ultra-dense networks (5G UDN) is considered as a promising architecture and also the key to the IoT era.

Studies on 5G UDN architecture and related technologies, control techniques, and resource allocation and management solutions. Particularly, techniques such as cluster, multi-tier, multicast, and device-to-device communication; as well as storage and spectral resource allocation and management solutions are studied to improve the spectral efficiency, enlarge the bandwidth, and expand the network coverage/connectivity. In addition, the control techniques of caching and delivering video attracts researchers in both academic research and industrial applications. However, these techniques either do not exploit the social relationship of device users, or have not controlled and managed optimally the process of reusing spectrum resources, or do not provide users with a strategy flexible video stream distribution location selection control.

From the above analysis, in this thesis, I proposed the NCS: 1) communication between devices in control systems is 5G mobile network; 2) the data in the system is video streaming ones (with large capacity). The joint optimal control of downlink resource sharing and caching selection for maximizing the capacity of multicast video streaming in 5G UDN. Optimal control solutions for multicast video streaming in 5G UDN through techniques of caching, spectrum resources sharing, device-to-device communications, and clustering with social relationships as well as ensuring the fairness of quality of services for device users (mobile users and IoT devices). An NCS video streaming optimization is proposed with the block diagram shown in Figure 1. In which, the optimal control unit is located at the macro base station (MBS) to control the caching itself, either in smallcell base stations (SBS), or on caching helper (CH) devices, or IoT devices and control spectrum resource of sharing user devices (SU) assisted D2DC multicast. Controller used information QoS feedback from mobile users (MU) to ensure the quality characterized by signal to noise ratio and interference (SINR) (γ_0) and guaranteeing fairness of video streaming capacity (σ_C) of MU at the allowed threshold. The optimal control signal is the indicator v* to the joint control caching location selection and spectrum resource sharing to provide users with maximum video streaming capacity C*. The proposed solution will utilize the caching and spectrum resources of the system to maximize the video streaming capacity distributed to IoT devices and MU, and ensure service fairness to MUs.

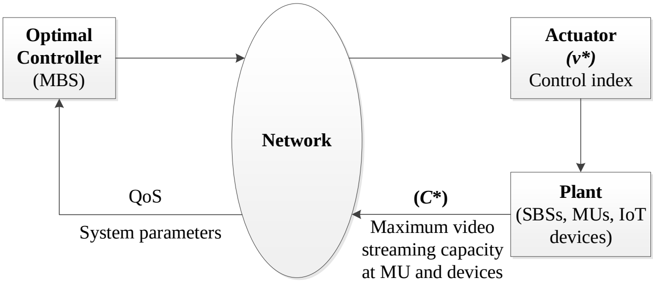

Figure 1. Block diagram of control system in 5G ultra-dense networks

2. Objectives, subjects, scope and research methods

2.1. Objective of research

The networked control system models that control data in NCS, namely multicast video streaming in 5G UDN maximized delivery capacity.

2.2. Subject of research

The research subject is the communication network in NCS, i.e., the 5G mobile network ultra-dense include: network architecture (5G UDN multi-tier there are many smallcell base station, very large quantity of mobile users and IoT devices), techniques (caching, delivering, sharing spectrum resources, D2D communication, clustering, multicast), mobile users and IoT devices (models of social relationships and QoS).

2.3. Scope of research

Optimal control video streaming in 5G UDN. Social relationships of mobile users, QoS is based on system capacity and resource efficiency. Models (Wireless channels and social relationship between mobile users), search Algorithms (exhaustive and heuristic).

2.4. Research methods

- Analyzing and evaluating the research situation: Find out related published research results in the field of data streaming control in networked systems.

- System formulation model of control: Compute model of system capacity, QoS evaluation criteria and resource performance, there by formulation optimal control problem for caching, sharing and distribution video streaming.

- Propose control methods: Research models, mathematical tools (especially distribution model, optimal mathematical theory, optimal search algorithm, and analytical methods of solving complexity).

- Simulation and evaluation of results: simulate, verify and evaluate the effectiveness through comparison with other related solutions. The proposed solution is feasible to install and deploy in 5G UDN as well as propose centralized or distributed control modalities suitable for controlling caching, sharing and distribution of video streaming appropriately in the NCS.

3. Research tasks, achieved results

3.1. Research tasks

- Propose models of data control in NCS, i.e., multi-tier video streaming control based on multicast communication in 5G UDN.

- Computational modeling of system parameters in terms of capacity, QoS, and resource performance, and service fairness, taking into account the MU social relationship.

- Develop and solve the problem of optimal resource sharing and caching control for multi-tier video streaming based on multicast communication in 5G UDN.

- Implement simulation, verify, and evaluate the effectiveness of the proposed solution compared with related solutions.

3.2. Achieved results

Proposing the optimal control model of data in the NCS, specifically the multicast video streaming control model in 5G UDN.

4. Thesis structure

Introduction

Chapter 1: Overview of the Networked Control System.

Chapter 2: Overview of Genetic Algorithms in the problem of video streaming optimal control.

Chapter 3: Optimal Control of Downlink Resource Sharing and Caching Helper Selection of Multicast Video Streaming in 5G UDN

Chapter 4: Optimal Control of Social-Aware Spectrum Sharing and Caching Helper Selection of Multicast Video Streaming in 5G UDN.

Chapter 5: Optimal Control of Downlink Resource Sharing and Multi-tier Caching Selection of Multicast Video Streaming in 5G UDN.

Conclusion

CHAPTER 1 OVERVIEW OF THE NETWORKED CONTROL SYSTEM

1.1 Overview of the Networked Control System

NCS is a control system in which control loop are transmitted over the network. The function of NCS is set up by 4 basic elements: sensor, controller, actuator and communication network. The most important feature of the NCS is that it connects in the communication network space allowing a number of remote tasks to be performed, eliminating unnecessary physical connections in order to reduce the complexity and overhead of the installation design and operation. NCS can also easily modify or upgrade and optimize by adding/removing elements and algorithms without making major changes in their structure. Moreover, with efficient data sharing between elements, NCS can easily consolidate information on a large scale to make intelligent decisions.

1.2 Overview of 5G UDN

5G mobile ultra-dense network (5G UDN) is an information network with a very large number of mobile base stations, connected devices and users, depicted in Figure 1.1. In particular, there are many advanced applications and services that consume a lot of transmission capacity.

With a multi-tier architecture, 5G UDN provides more network space and coverage thanks to intermediate the SBSs, flexibly combining the available resources of the network and the resources of shared users to ensure connectivity high speed in 5G UDN. However, 5G UDN still has challenges in the process of using and exploiting resources. Therefore, 5G UDN must be designed and built to ensure optimal resources, improve mobile network quality and improve user satisfaction.

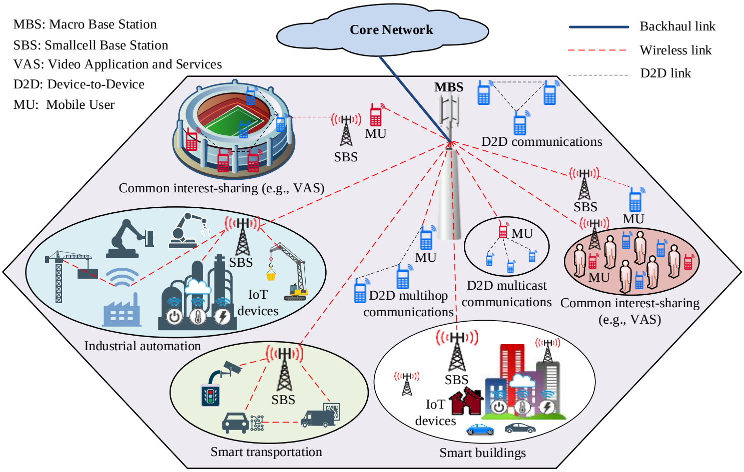

Figure 1.1. Architecture and applications in 5G UDN

1.3 Transmission video in 5G UDN

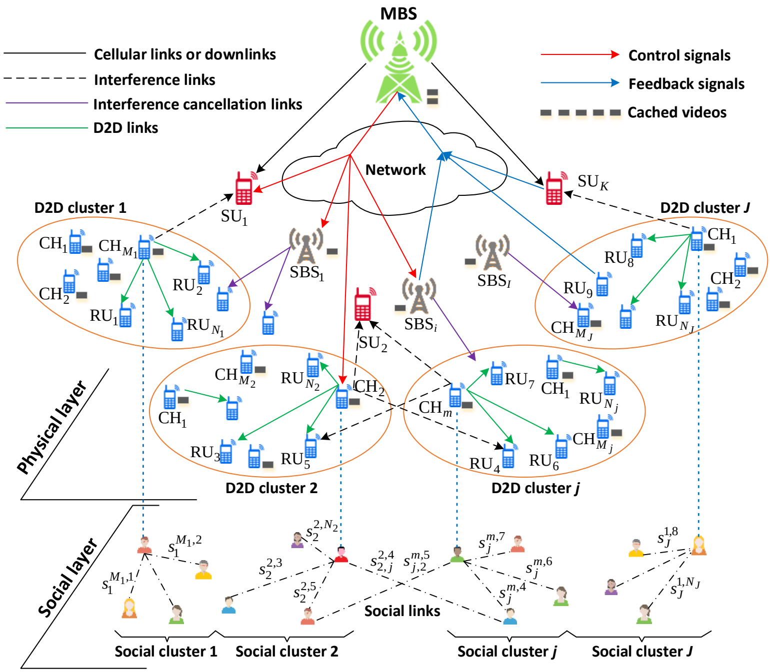

Figure 1.2. Models control for video transmission in 5G UDN

MUs can receive video streaming from 3 floors including: from MBS, SBSs, or other MUs via D2D communication. The cascade selection control is done by the MBS.

1.4 Wireless Channel

The wireless channel model is the channel gain determined by the product of the two components: the exponential power fading coefficient and the standard power law path loss function with path loss. The exponential power fading coefficient [66] power fading coefficient with unit mean 1 (~ exp(1)). The standard power law path loss function with path loss $d^{(-\eta)}$, d is the distances from the transmitter to receiver, η is a path loss exponent.

1.5 Social relationship model

Basic social attributes are characterized by the degree of interaction between MUs, that is, the number of interactions and the duration of each connection. To get this relationship, I applied Indian Buffet Model (IBM) [70]–[74] to establish social relationships between MUs.

1.6 Video streaming multicast

The multicast video transmission model utilizes 2 characteristics: 1) broadcasts of radio signals and 2) D2D communication within close proximity to users who are interested in the same content and ready to share. This model is effective for VAS applications in office buildings, meeting rooms, stadiums, ... where user density is high.

1.7 Related works

Different clustering techniques focus on different goals to achieve high system performance: expanded communication coverage [12]–[15], low latency [16], spectral efficiency high frequency and energy efficiency [11], [17]–[22], [45], [46], the probability of successfully accessing content and high system capacity [23]–[25]. Process of selecting the best transmitters is necessary to achieve higher system performance [11], [21]. A multicast D2D communication technique serving users in a cluster who require the same video content will save more energy resources and spectrum. However, the multicast D2D communication technique causes higher QoS inequality among users [39], [41], [47]–[51]. The problem that exists is not considering the social attributes of the device user.

The techniques of clustering control and multicast transmission considering the social attributes of users are presented [38], [40], [67], [75]–[79]. However, these studies have not combined the use of spectrum resources, clustering and multicast transmission.

1.8 Conclusion of chapter 1

An overview of the networked control system was introduced; a brief presentation on 5G UDN; provide an overview of the system's physical properties and the user's social attributes; as well as the concepts of caching, control and sharing of spectrum resources, clustering, selection, D2D communication, multicast D2D communication.

CHAPTER 2 OVERVIEW OF GENETIC ALGORITHMS IN THE PROBLEM OF VIDEO STREAMING OPTIMAL CONTROL

2.1 Overview of optimal search algorithms

In mathematics, there are many methods to solve optimal problems for accurate results, but the resources and time to search are complicated for a large search space. Heuristic algorithm applied to solve optimal problems based on experience to solve problems, learn or explore in order to provide an acceptable approximate solution with a reasonable calculation time.

2.2 Overview of Genetic Algorithms (GAs)

2.2.1 Introduction

The GA is a stochastic global search method that mimics the metaphor of natural biological evolution.

2.2.2 GAs versus Traditional Methods

The four most significant differences are:

- GAs search a population of points in parallel, not a single point.

- GAs do not require derivative information or other auxiliary knowledge; only the objective function and corresponding fitness levels influence the directions of search.
- GAs use probabilistic transition rules, not deterministic ones.
- GAs work on an encoding of the parameter set rather than the parameter set itself (except in where real-valued individuals are used).

2.3 Flowchart and Major Elements of the Genetic Algorithm

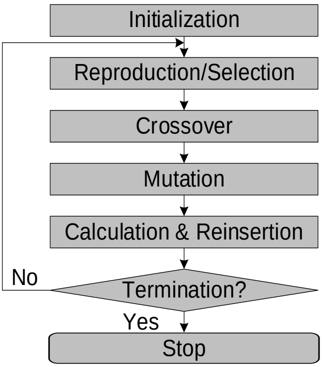

Fig 2.1. Flowchart of GA

Step 1 - Initialization: Population Representation and Initialisation. The objective function is used to provide a measure of how individuals have performed in the problem domain.

Step 2 - Reproduction/Selection: the individuals with the higher objective function were selected for crossover and mutation.

Step 3 - Crossover: To propagate

Step 4 - Mutation: to restore good genetic traits likely to have been lost in previous processes.

Step 5 - Calculation & Reinsertion: The objective function values are re-calculated individually and checked whether the convergence condition is hold.

2.4 Problems applying GAs in video streaming

The authors in [45], [66], [82]–[84] applied GA to the problems of controlling video streaming in wireless network effectively.

2.5 Conclusion of chapter 2

It is the basis for applying GAs to the video streaming problem in the proposed models.

CHAPTER 3 OPTIMAL CONTROL OF DOWNLINK RESOURCE SHARING AND CACHING HELPER SELECTION OF MULTICAST VIDEO STREAMING IN 5G UDN

3.1 Overview of DRS-CHS

In 5G ultra-dense networks, a large number of mobile users (MUs) request a huge amount of high data rate video traffic causing a peak congestion situation at the macro base station (MBS) and small-cell base stations. This situation certainly reduces the total video capacity delivered to the MUs. I exploit the available spectrum and caching resources of the MUs as well as the wireless broadcast nature of device-to-device (D2D) communications to propose a joint downlink resource sharing and caching helper selection (DRS-CHS) control to maximize the multicast video delivery capacity in dense D2D 5G networks. I assume that the MUs are divided into different clusters in which they can communicate with each other by D2D communications. There are two types of MUs in each cluster including the requesting users (RUs) that request the video and the caching helpers (CHs) that have cached the video. In addition, there are some sharing users (SUs) that can share their downlink resources with the CHs and the RUs for D2D multicast communications. A DRS-CHS optimization problem is then formulated and solved for an optimal control process of how to select a CH in each cluster and how to assign an SU to share its downlink resource with the selected CH such that the total video delivery capacity multicasted from the CHs to the RUs in all clusters is maximized.

3.2 System Model and System Formulations of DRS-CHS

3.2.1 System Model of DRS-CHS

System model of DRS-CHS as shown in Figure 3.1. The model consists of one MBS and K SU that share the downlink resources with J D2D clusters for D2D multicast communications. The D2D cluster j has M_j CH have cached the requested video and N_j RU request the video for streaming and CH m is optimally selected to provide N_j RUs with maximum video delivery capacity.

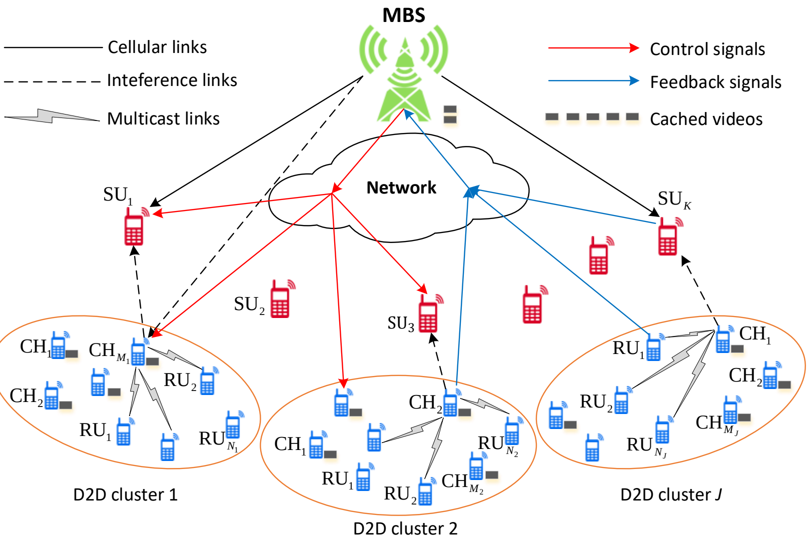

Figure 3.1. System model of DRS-CHS

The MBS receives a number of demands for the video, the DRS-CHS scheme is initiated to work in 3 steps as follows:

- Step 1 – Clustering D2D users: the MBS divides the D2D users into J cluster to expand the coverage. MBS checks if a D2D user has cached the requested video or not. As a result, the cluster j has M_j CH and N_j RU which are in close proximity for D2D communications.
- Step 2 – Solving DRS-CHS optimization problem: The MBS further collects the characteristics of wireless channels between devives. The MBS formulates the DRS-CHS optimization problem and solves it for optimal downlink resource sharing and caching helper selection index $v_j^{k,m}$ ($v_j^{k,m}$ = 1(0) means the SU k shares its downlink resource with the CH m for multicasting the video to N_j RU in cluster j and otherwise). There are three constraints considered including:

i) $\sum_{k=1}^{K}\sum_{m=1}^{M_j} v_j^{k,m} \leq 1, j = 1, 2, \ldots, J$ to ensure that one SU can share its downlink resource up to one CH in each cluster;

ii) $\sum_{j=1}^{J}\sum_{m=1}^{M_j} v_j^{k,m} \leq 1,\ k = 1, 2, \ldots, K$ so that one SU cannot share its downlink resource with more than one CH in J clusters;

iii) the target SINR at the SUs is guaranteed, i.e., greater than or equal to a given threshold γ_0, to limit the interference impact caused by multicast D2D communications on the capacity performance of SUs.

- Step 3 – Mulitcating requested video: After finding $v_j^{k,m}$, the corresponding SUs and CHs are assigned to multicast the requested video to the RUs at maximum video delivery capacity. It is noted that if the requested video is not in any clusters, it is delivered by the MBS.

3.2.2 System Formulations of DRS-CHS

To compute the signal to interference plus noise ratio (SINR) at RUs

$$\gamma_j^{k,m,n} = \frac{v_j^{k,m} P_j^m G_j^{m,n}}{N_0 + P^{0,k} G_j^{0,n}} \tag{3.2}$$

where $v_j^{k,m}$ is control index; P_j^m, $P^{0,k}$ is the transmission power of the CH *m* in cluster *j* and transmission power MBS to SU *k*; $G_j^{m,n}$, $G_j^{0,n}$ is the channel gain between the CH *m* and MBS to RU *n* in cluster *j*; N_0 is the power of additive white Gaussian noise.

The signal to noise ratio MBS to RU *n*

$$\gamma_j^{0,n} = \frac{(1 - \sum_{k=1}^{K} \sum_{m=1}^{M_j} v_j^{k,m}) P_j^{0,n} G_j^{0,n}}{N_0} \tag{3.3}$$

where $P_j^{0,n}$ is the transmission power of the MBS to the RU *n* in cluster *j*.

The total multicast capacity delivered to the RUs is given by

$$C_{RU} = W \sum_{j=1}^{J} \left[\sum_{k=1}^{K} \sum_{m=1}^{M_j} \sum_{n=1}^{N_j} \log_2(1 + \gamma_j^{k,m,n}) + \sum_{n=1}^{N_j} \log_2(1 + \gamma_j^{0,n}) \right] \tag{3.4}$$

where *W* is the system bandwidth.

3.3 DRS-CHS optimization problem and solution

3.3.1 DRS-CHS optimization problem

Objective function (3.4) which is maximized by finding the optimal value of $v_j^{k,m}$.

$$\max_{v_j^{k,m}} C_{\mathrm{RU}} \tag{3.6}$$

$$s.t.\begin{cases} \sum_{k=1}^{K}\sum_{m=1}^{M_j} v_j^{k,m} \le 1, j = 1,2,\dots,J \\ \sum_{j=1}^{J}\sum_{m=1}^{M_j} v_j^{k,m} \le 1, k = 1,2,\dots,K \\ v_j^{k,m} P_j^m G_j^{m,k} \le \dfrac{P^{0,k}G^{0,k}}{\gamma_0} - N_0, k = 1,2,\dots,K, \\ j = 1,2,\dots,J, m = 1,2,\dots,M_j \end{cases} \tag{3.7}$$

The above DRS-CHS optimization problem can be simply solved by using exhaustive searching algorithm (EA). However, when the network size is large, the EA algorithm will have increased memory complexity and computation time.

3.3.2 DRS-CHS optimization problem using GA

Apply penalty method and change the searching in R to searching in binary. To do so, I rewrite the constraints of (3.7) in sequence as:

$$\begin{cases} \Delta V_j = 1 - \sum_{k=1}^{K}\sum_{m=1}^{M_j} v_j^{k,m} \ge 0, j = 1,2,\dots,J \\ \Delta V_k = 1 - \sum_{j=1}^{J}\sum_{m=1}^{M_j} v_j^{k,m} \ge 0, k = 1,2,\dots,K \\ \Delta\gamma^k = \dfrac{P^{0,k}G^{0,k}}{\gamma_0} - N_0 - v_j^{k,m} P_j^m G_j^{m,k} \ge 0, k = 1,2,\dots,K, \\ j = 1,2,\dots,J, m = 1,2,\dots,M_j \end{cases} \tag{3.8}$$

We then obtain the penalty function expressed as

$$P = \lambda_1 \sum_{j=1}^{J} \left(\min\{0, \Delta V_j\}\right)^2 + \lambda_2 \sum_{k=1}^{K} (\min\{0, \Delta V_k\})^2 + \lambda_3 \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M_j} (\min\{0, \Delta\gamma^k\})^2 \tag{3.9}$$

where λ_1, λ_2, λ_3, are to reflect the penalty degree of the constraints.

So far, instead of solving (3.6) and (3.7), GA can be applied to solving the following unconstrained DRS-CHS optimization problem

$$\max_{v_j^{k,m}} C = C_{\mathrm{RU}} - P \tag{3.10}$$

3.4 Performance Evaluation

We deploy the proposed system with the parameters given in Table 3-2. In addition, the distances from the MBS to the MUs, the CHs to the SUs, the CHs to the RUs are respectively distributed in the ranges of [100, 1000] m, [50, 100] m and [1, 50] m.

Table 3-2. Parameters setting for DRS-CHS optimization problem

Symbols	Specifications	Symbols	Specifications GA
K	5 SU	N_P	15000
J	5 cluster	N_G	50
$\{M_j\}$	{2, 4, 6, 8, 10} CH	N_V	1
$\{N_j\}$	{5, 10, 15, 20, 25} RU	N_B	$K\sum_{j=1}^{J} M_j$
W	5MHz	P_G	0.8
N_0	10^{-13} W	P_C	0.8
γ_0	5dB	P_M	10^{-9}
$P^{0,k}$, $P_j^{0,n}$	5W	λ_1	10^5
P_j^m	Randomly distributed from 0.001W to 0.1W	λ_2	10^5
η	4	λ_3	10^{22}

To evaluate the system performance, I compare the proposed DRS-CHS solution to other three benchmarks including capacity of RUs served by only MBS (OMBS), average capacity of RUs (Ave), and minimum capacity of RUs (Min).

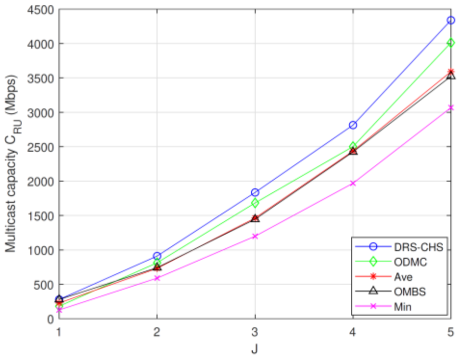

Fig. 3.4. System performance versus the number of clusters J

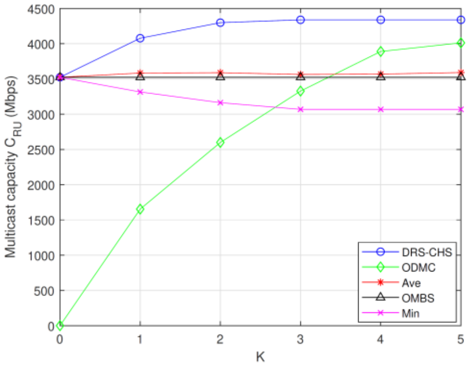

Fig 3.5. System performance versus the number of SUs K

Figure 3.4, the increase of number of clusters J enables more RUs to be served by the CHs over multicast D2D communications. As a result, the system performance increases with respect to J.

Figure 3.5, when increasing the number of SUs, there are more proper possibilities to select the best set of SUs and CHs to maximize the system performance and thus, the proposed DRS-CHS is always the best.

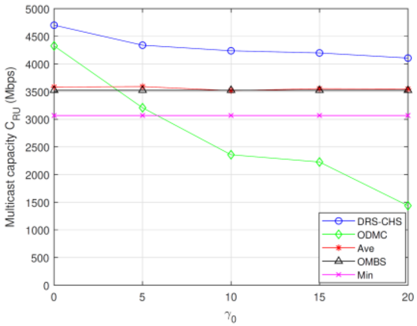

Fig. 3.6. System performance versus the target SINR of SUs γ_0

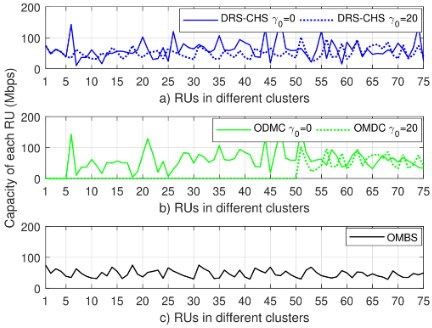

Fig. 3.7. Capacity fluctuation amongst the RUs

Figure 3.6, increasing (γ_0) means that the target SINR of SUs is higher to guarantee higher QoS for the SUs. As a result, the number of SUs agrees to share their downlink resources decreases making the performance of DRS-CHS degraded but keeping the highest total multicast capacity compared to OMBS, Ave, and Min.

For a more efficient solution, a capacity fluctuation constraint must be considered in the DRS-CHS optimization problem to limit the capacity fluctuation is show Figure 3.7.

3.5 Conclusion of chapter 3

The DRS-CHS is flexible to control: 1) The RUs to be served whether by the MBS or the CHs over clustered based multicast D2D communications with downlink resource sharing; 2) It also optimally controls the process of selecting the proper set of SUs and CHs so as to provide the RUs with maximum multicast video delivery capacity.

CHAPTER 4 OPTIMAL CONTROL OF SOCIAL-AWARE SPECTRUM SHARING AND CACHING HELPER SELECTION OF MULTICAST VIDEO STREAMING IN 5G UDN

4.1 Overview of SSC

One of the most efficient solutions is resource allocation that does not require any network architecture changes. In this chapter, I propose a social-aware spectrum sharing and caching helper selection (SSC) strategy that exploits the resources of the MUs, i.e., downlink spectrum resources for sharing and caching storage resources for multicasting, to offload the videos in dense device-to-device (D2D) 5G networks. Particularly, we take into account both physical and social attributes of the MUs to formulate an SSC optimization problem. The SSC problem is solved by applying genetic algorithms to optimally control: 1) which MUs, namely sharing users (SUs), that share the downlink spectrum resources and 2) which MUs, namely caching helpers (CHs), that cache the requested videos for D2D multicast communications by reusing the shared downlink spectrum resources. The objective is to maximize the system capacity while simultaneously satisfying a given capacity fluctuation limit amongst the receiving users (RUs) and a given target signal to interference plus noise ratio (SINR) at the SUs, to guarantee the RUs and the SUs high QoS fairness.

So, this strategy is an extension of the model proposed in Chapter 3 by 1) further consideration of the social relationship between users, 2) the constraint on capacity fluctuations between RUs and the effects of caused by CH acts on RUs in different clusters when implementing multicast D2DC to ensure fairness of QoS for the RUs, and 3) SU's downlink resources are exploited more effectively because one SU can share its downlink resource with more than one CH in different clusters.

4.2 System Model and System Formulations of SSC

4.2.1 System model

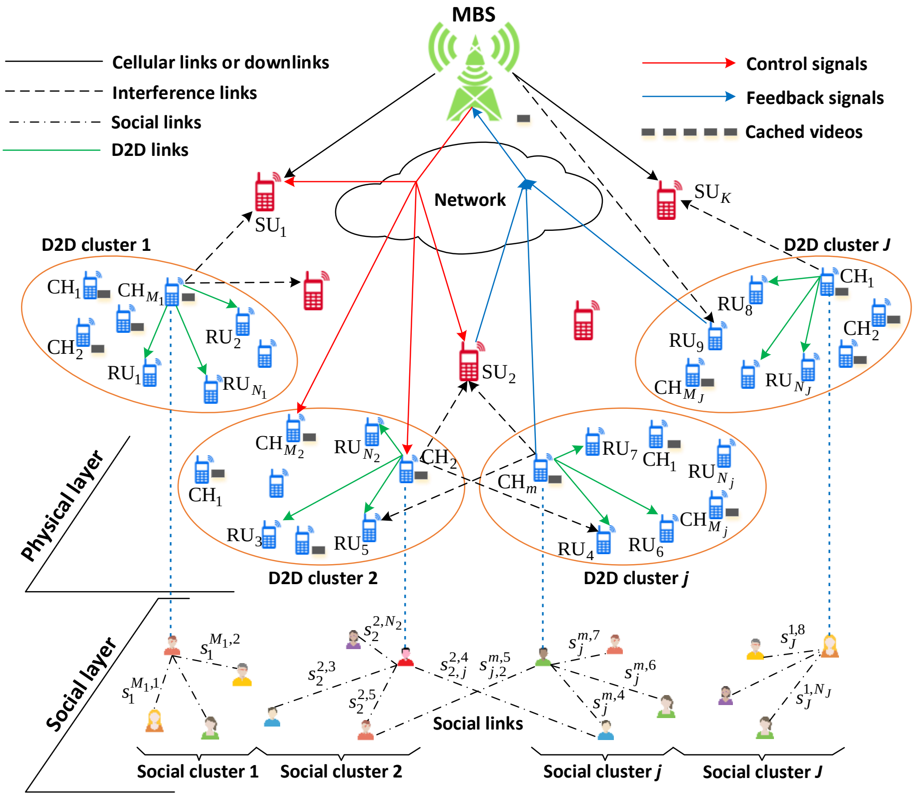

Figure. 4.2. System model of SSC

The system of multicast video streaming in dense D2D 5G networks with SSC as shown in Figure 4.2 is separated into physical layer and social layer. The physical layer consists of one MBS, K SU and J clusters has M_j CH and N_j RU. Mapping from the physical layer, we take into account the social layer that provides the social relationships between the CHs and the RUs for more efficient SSC strategy. The SSC strategy performs the following three phases:

- Clustering: the MBS establishes J clusters, in cluster has M_j CH and N_j RU that are in direct D2D communications.

- Sharing and selecting: the MBS collects the parameters of system as shown in Table 4-2 to formulate the SSC optimization problem, is solved for optimal binary index $v_j^{k,m}$ with constraints for efficient exploitation of resources, capacity fluctuation between RUs (σ^*) and threshold (γ_0) SINR at the SUs is guaranteed.

- Multicasting: After obtaining the optimal index $v_j^{k,m}$ the MBS controls the process of spectrum resource sharing and caching helper selection assigned to the SUs and the CHs so that the requested video is multicasted from the CHs to the RUs in all clusters at the highest system performance.

Table 4-2. Notations

Symbols	Specifications
J	Number of clusters
K	Number of SUs
M_j	Number of CHs in the cluster j, $j = 1, 2, \ldots, J$
N_j	Number of RUs in the cluster j
W	System bandwidth
N_0	Power of additive white Gaussian noise
γ_0	Target SINR of SUs
$P^{0,k}$	Transmission power of the MBS to the SU k, $k = 1, 2, \ldots, K$
$P_j^{0,n}$	Transmission power of the MBS to the RU n in cluster j, $n = 1, 2, \ldots, N_j$
P_j^m	Transmission power of the CH m in cluster j
η	Path loss exponent
$d_j^{0,n}$, $d_j^{m,n}$	Distances from the MBS (indicated by 0) and the CH m to the RU n in cluster j
$d_{j'}^{m',n}$	Distances from the MBS CH m' in cluster j' to the RU n in cluster j
d_0^k, $d_j^{m,k}$	Distances from the MBS (indicated by 0) and the CH m to the SU k
T_j	Length of requested video in the cluster j (second)
$\kappa_j^{m,n}, \theta_j^{m,n}$	Shape and scale parameters of Gamma-based encounter duration distribution
$s_j^{m,n}$	Social-aware success probability to send the video of length T_j from the CH m to the RU n in cluster j

4.2.2 System formulations of SSC

The signal to interference plus noise ratio (SINR) at RUs

$$\gamma_j^{k,m,n} = \frac{v_j^{k,m} s_j^{m,n} P_j^m G_j^{m,n}}{N_0 + P^{0,k} G_j^{0,n} + I_C^{k,n}} \tag{4.10}$$

where $I_C^{k,n}$ is the interference from the transmissions of the CHs in other clusters

$$I_C^{k,n} = \sum_{\substack{j'=1 \\ j'\neq j}}^{J} \sum_{m'=1}^{M_{j'}} v_{j'}^{k,m'} s_{j'}^{m',n} P_{j'}^{m'} G_{j'}^{m',n} \tag{4.11}$$

In case if the SUs do not share their downlink resources, SNR at RUs

$$\gamma_j^{0,n} = \frac{\prod_{k=1}^{K} \prod_{m=1}^{M_j} \left(1 - v_j^{k,m} s_j^{m,n}\right) P_j^{0,n} G_j^{0,n}}{N_0} \tag{4.12}$$

The total video capacity at the RUs

$$C_{RU} = W \sum_{j=1}^{J} \left[\sum_{k=1}^{K} \sum_{m=1}^{M_j} \sum_{n=1}^{N_j} C_j^{k,m,n} + \sum_{n=1}^{N_j} C_j^{0,n} \right] \tag{4.13}$$

where W is the system bandwidth and

$$C_j^{k,m,n} = \log_2(1 + \gamma_j^{k,m,n}) \tag{4.14}$$

$$C_j^{0,n} = \log_2(1 + \gamma_j^{0,n}) \tag{4.15}$$

* Capacity fluctuation among RUs

$$\sigma_C = \sqrt{\frac{\sum_{j=1}^{J} \left\{ \sum_{n=1}^{N_j} \left[W \left(\sum_{k=1}^{K} \sum_{m=1}^{M_j} C_j^{k,m,n} + C_j^{0,n} \right) - \bar{C}_{RU} \right]^2 \right\}}{\sum_{j=1}^{J} N_j}} \tag{4.16}$$

where

$$\bar{C}_{RU} = \frac{C_{RU}}{\sum_{j=1}^{J} N_j} \tag{4.17}$$

* SINR at SUs

$$\gamma^k = \frac{P^{0,k} G^{0,k}}{N_0 + \sum_{j=1}^{J} \sum_{m=1}^{M_j} v_j^{k,m} P_j^m G_j^{m,k}} \tag{4.18}$$

4.3 Optimization problem of SSC and GA solution

4.3.1 Optimization problem of SSC

SSC optimization problem is maximized objective function (4.13) indicator index $v_j^{k,m}$ with 3 constraints: efficient exploitation of resources, capacity fluctuations between RUs (σ^*) and threshold (γ_0) SINR at the SUs is guaranteed.

$$\max_{v_j^{k,m}} C_{RU} \tag{4.19a}$$

$$s.t.\begin{cases} \sum_{k=1}^{K}\sum_{m=1}^{M_j} v_j^{k,m} \leq 1, \forall j \; = \; 1,2,\dots,J \\ \sigma_C \leq \sigma^*, \\ \sum_{j=1}^{J}\sum_{m=1}^{M_j} v_j^{k,m} P_j^m G_j^{m,k} \leq \dfrac{P^{0,k}G^{0,k}}{\gamma_0} - N_0, \\ k \; = \; 1,2,\dots,K \end{cases} \tag{4.19b}$$

4.3.2 Optimization problem of SSC using GAs

Apply penalty method and change the searching in R to searching in binary. To do so, I rewrite the constraints of (4.19b) in sequence as:

$$s.t.\begin{cases} \Delta V_j = 1 - \sum_{k=1}^{K}\sum_{m=1}^{M_j} v_j^{k,m} \geq 0, j \; = \; 1,2,\dots,J \\ \Delta\sigma = \sigma^* - \sigma_C \geq 0, \\ \Delta\gamma^k = \dfrac{P^{0,k}G^{0,k}}{\gamma_0} - N_0 - \sum_{j=1}^{J}\sum_{m=1}^{M_j} v_j^{k,m} P_j^m G_j^{m,k} \geq 0, \\ k \; = \; 1,2,\dots,K \end{cases} \tag{4.20}$$

Then, the penalty function is given by

$$P = \lambda_1 \sum_{j=1}^{J} \left(\min\{0, \Delta V_j\}\right)^2 + \lambda_2 (\min\{0, \Delta\sigma\})^2 + \lambda_3 \sum_{k=1}^{K} (\min\{0, \Delta\gamma^k\})^2 \tag{4.21}$$

where λ_1, λ_2, λ_3, are to reflect the penalty degree of the constraints.

Finally, instead of maximizing (4.19), I can be applied GAs solution to maximize the following unconstrained optimization problem

$$\max_{v_j^{k,m}} C = C_{RU} - P \tag{4.22}$$

4.4 Performance evaluation

We deploy the proposed system with the parameters given in Table 4-3, the distances from the MBS to the MUs, the CHs to the SUs, the CHs to the RUs are respectively distributed in the ranges of [100, 1000]m, [100, 500]m, [1, 50]m, [1, 300]m và [50, 150]m. In addition, $\lambda_1 = 10^6$, $\lambda_2 = 10^6$ và $\lambda_3 = 10^{32}$.

Table 4-3. Parameters setting for optimization problem of SSC

Symbols	Specifications
J	5 clusters
K	5 SUs
$\{M_j\}$	{2, 4, 6, 8, 10} CH
$\{N_j\}$	{5, 10, 15, 20, 25} RU
W	5Mhz
N_0	10^{-13}W
γ_0	10dB
σ^*	25
$P^{0,k}$, $P_j^{0,n}$	5W
P_j^m	Randomly uniform distributed from 0.01W to 0.1W
η	4
$\{T_j\}$	{20, 10, 15, 13, 5}s
$\kappa_j^{m,n}$	Randomly uniform distributed from 1 to 10
$\theta_j^{m,n}$	Randomly uniform distributed from 1 to 30
N_P	10,000
N_G	100
N_V	1
N_B	$K \times \sum_{j=1}^{J} M_j$
P_G	0.9
P_C	0.9
P_M	10^{-8}

4.4.1 Convergence rate of GA

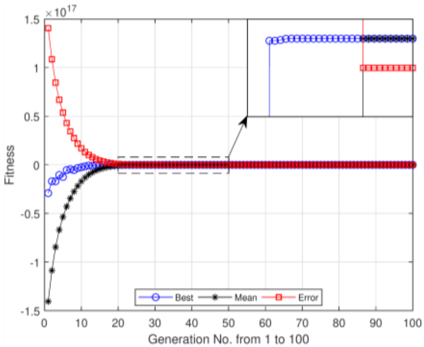

Fig 4.3. Convergence rate of GAs

Fig 4.3, the GA quickly get convergence after 20 generations. The fast convergence rate proves that GA is feasible for solving the SSC problem in 5G UDN.

Performance of GA continue to be evaluated by cluster number (J) and population size (N_P) in Table 4-4 and Table 4-5.

Table 4-4. GA convergence time (s) versus J and N_P

N_P / J	100	500	1000	5000	10000
1	0,27	0,40	0,66	4,61	17,67
3	N/A	5,76	13,00	65,78	158,99
5	N/A	44,55	113,53	486,83	930,50

Table 4-5. GA accuracy (%) versus J and N_P

N_P / J	100	500	1000	5000	10000
1	100	100	100	100	100
3	N/A	100	100	100	100
5	N/A	90,09	96,32	100	100

4.4.2 System performance of SSC

To evaluate the performance of the proposed SSC, we compare it to other schemes including non-social-aware spectrum sharing and caching helper selection (NSA), only MBS (OMB), average performance (AVE), and minimum performance (MIN).

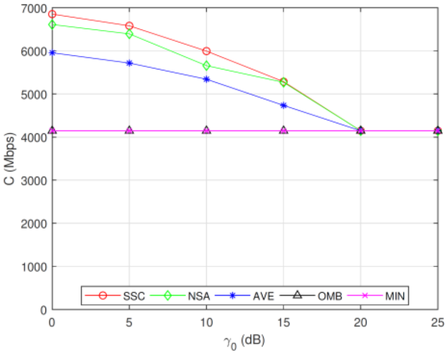

Fig 4.4. System capacity versus the target SINR of SUs γ_0

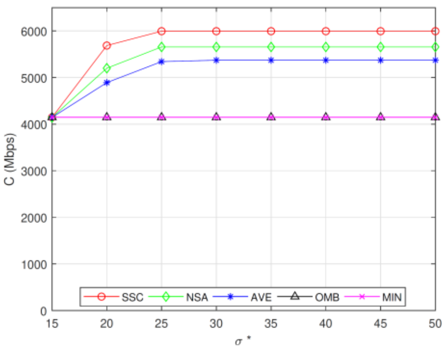

Fig 4.5. System capacity versus the standard deviation of capacity σ^*

Fig 4.4*Fig 4.*, if γ_0 is low system for high capacity and will saturate when γ_0 increasing. For performance evaluation such that the SSC gets the highest gain while guaranteering the SUs the high fairness with high SINR at γ_0 = 10dB.

Fig 4.5, system capacity increases when standard deviations are allowed σ^*, however will saturate when σ^* is highly.

Fig 4.6, system capacity increases when there are many clusters of users. High system performance when the number of clusters is large enough (J = 3, SSC gives better index than NSA, which means that social relationship factor can be exploited effectively in 5G UDN).

Fig 4.7 shows that increasing the number of users sharing spectrum will increase system performance and suggest model for best performance.

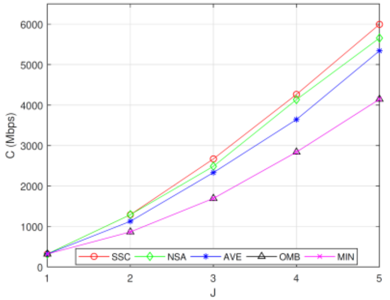

Fig 4.6. System capacity versus the number of clusters J

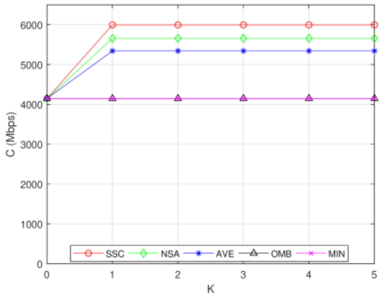

Fig 4.7. System capacity versus the number of SUs K

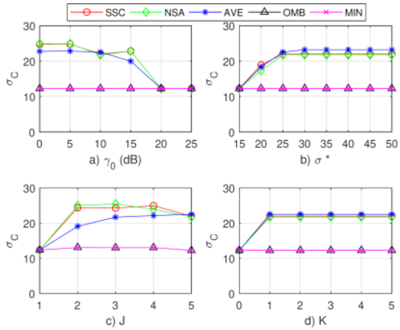

Fig 4.8. Standard deviation of capacity at the RUs

Fig. 4.8 shows the tradeoff of the proposed SSC system for the highest capacity but accepts high variation between RUs. Specifically, in Table 4-6, the equity comparison results are presented for two QoS equity constraints including the SINR threshold level at SUs. (γ_0) and standard deviation of capacity (σ^*)

Table 4-6. Fairness comparison at RUs

Scheme / Constraint	SSC	NSA	AVE	OMB	MIN
γ_0	Fair	Fair	Good	Excellent	Excellent
σ^*	Good	Good	Fair	Excellent	Excellent

4.5 Conclusion of chapter 4

SSC proposal strategy is easy to control: 1) Distribution capacity for RU from MBS or CH via multicast D2D communication; 2) SU does share the downslink resource for CHs to perform multicast D2D communication. The capacity provided by the system to the RUs is maximum while ensuring the fairness of capacity for the RU as well as ensuring high QoS for SUs.

CHAPTER 5 OPTIMAL CONTROL OF DOWNLINK RESOURCE SHARING AND MULTI-TIER CACHING SELECTION OF MULTICAST VIDEO STREAMING IN 5G UDN

5.1 Overview of DRS-MCS

Downlink Resource Sharing and Multi-tier Caching Selection (DRS-MCS) solution to allow mobile users (MU) to experience VAS over the multicast with the three-tier caching placements at the MBS, the FBSs, and the CHs as well as the downlink resources available at the SUs. In addition, to control selection SU and CH pairs the downlink resource sharing for multicast D2DC on the user device with multicast at the MBS as shown in Chapter 3. The proposed model considers additional caching placements at the FBSs for multicast communication. In this way, the DRS-MCS will allow the RU to receive more flexible video streaming with higher capacity.

5.2 System model of DRS-MCS

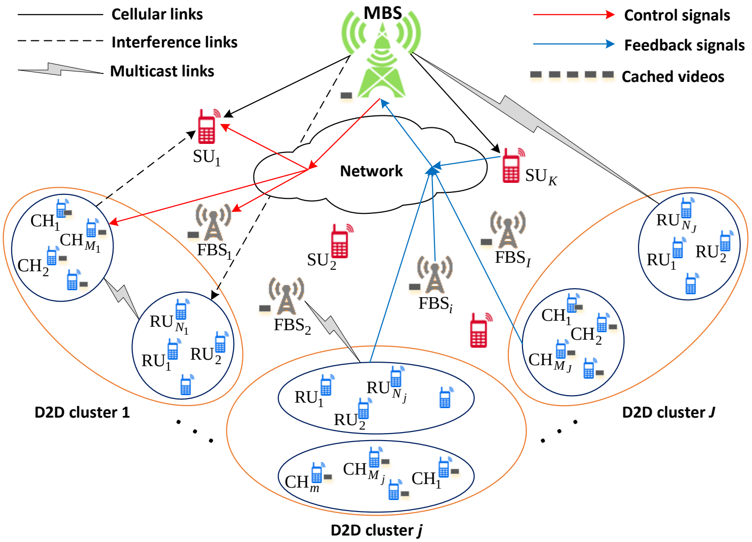

Figure 5.2. Multicast video streaming in 5G UDNs with DRS-MCS

System model include: one MBS, I FBS, K SU and J clusters. In cluster J has M_j CH cached the required videos and N_j RU request video.

5.3 System formulation of DRS-MCS

The total system capacity delivered from the MBS, FBSs, and CHs to the RUs in all clusters is expressed as:

$$C_{RU} = \sum_{j=1}^{J} \max\left\{ \sum_{n=1}^{N_j} C_j^{0,n}, \max\{\sum_{n=1}^{N_j} C_j^{i,n}, i = 1,2,\ldots,I\}, \sum_{k=1}^{K}\sum_{m=1}^{M_j}\sum_{n=1}^{N_j} C_j^{k,m,n} \right\} \quad (5.7)$$

5.4 DRS-MCS optimization problem and solution

DRS-MCS optimization problem is formulated as below

$$\max_{v_j^{k,m}} C_{RU} \quad (5.9a)$$

$$\text{s.t} \sum_{k=1}^{K}\sum_{m=1}^{M_j} v_j^{k,m} \le 1, j = 1,2,\ldots,J, \quad (5.9b)$$

$$\sum_{j=1}^{J}\sum_{m=1}^{M_j} v_j^{k,m} \le 1, k = 1,2,\ldots,K, \quad (5.9c)$$

$$v_j^{k,m} P_j^m G_j^{m,k} \le \frac{P^{0,k} G^{0,k}}{\gamma_0} - N_0, k = 1,2,\ldots,K, \quad j = 1,2,\ldots,J, m = 1,2,\ldots,M_j, \quad (5.9d)$$

Algorithm 1. EBSA for DRS-MCS optimization problem

Input: Initial system parameters
Output: V^*, C^*

Generating J search space matrices
$V_1 = \{V^1_{M_1\times K}, V^2_{M_1\times K}, \ldots, V^{2^{M_1\times K}}_{M_1\times K}\}$
$V_2 = \{V^1_{M_2\times K}, V^2_{M_2\times K}, \ldots, V^{2^{M_2\times K}}_{M_2\times K}\}$
…
$V_J = \{V^1_{M_J\times K}, V^2_{M_J\times K}, \ldots, V^{2^{M_J\times K}}_{M_J\times K}\}$
$C^* \leftarrow 0$
for each matrix v_1 in V_1, $v_1 = 1, 2, \ldots, 2^{M_1\times K}$ **do**
  for each matrix v_2 in V_2, $v_2 = 1, 2, \ldots, 2^{M_2\times K}$ **do**
    …
    for each matrix v_J in V_J, $v_J = 1, 2, \ldots, 2^{M_J\times K}$ **do**
      if J matrices satisfy (5.9b), (5.9c) and (5.9d) **then**
        Computing C in (5.7)
        if $C > C^*$ **then**
          $C^* \leftarrow C$
          $V^* \leftarrow \{V^{v_1}_{M_1\times K}, V^{v_2}_{M_2\times K}, \ldots, V^{v_J}_{M_2\times K}\}$

```
                    end if
                end if
            end for
            …
        end for
    end for
```

5.5 Performance evaluation of DRS-MCS

To evaluate the performance of the proposed DRS-MCS solution, we compare it to other schemes including average capacity (AVE), minimum capacity (MIN), without downlink resource sharing (Non-DRS), and only MBS (OMBS). The simulation results are shown in Fig 5.2, Fig 5.3, Fig 5.4 and Fig 5.5 shows the proposed solution for higher capacity at RUs.

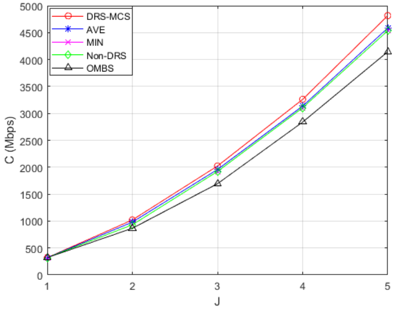

Fig. 5.3. System performance versus the number of clusters J

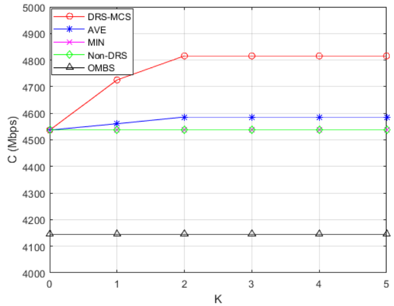

Fig. 5.4. System performance versus the number of SUs K

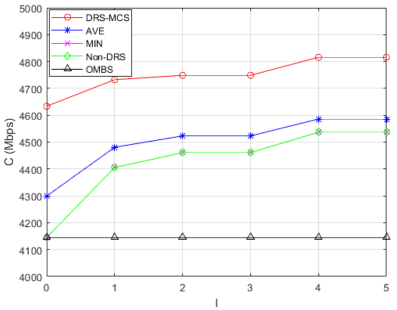

Fig. 5.5. System performance versus the number of FBSs I

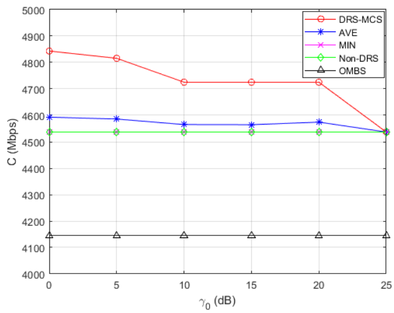

Fig. 5.6. System performance versus the number of FBSs γ_0

5.6 Conclusion of chapter 5

The proposed DRS-MCS not only allows for control of RUs that receive flexible video streaming over multicast communication from three-tier caching placements at the MBS, the FBSs, and the CHs, but also allows the SUs shares the available downlink resources with the CH that video streaming for multicast D2DC. In addition, useful recommendations regarding the selection of system parameters are included for the optimal design improvements of the DRS-MCS solution.

CONCLUSION

The thesis focuses on researching and proposing an optimal control model for distribution of multicast video streaming in 5G ultra-dense network (5G UDN) in order to improve the quality of service (QoS) and efficient use of caching resources as well as spectrum resources. The specific results obtained include : 1) the thesis has proposed an optimal control of multicast video streaming model to maximize capacity at the Requesting User (RU) with regard to QoS fairness of downlink resource Sharing User (SU) in 5G UDN; 2) improving the proposed model by: i) paying attention to the social relationships of the Caching Helper (CH) and RU; ii) more efficient utilization of SU's spectrum resources, i.e., one SU can share with more than one CH in many different clusters, as long as fairness of QoS is guarantee for SUs; iii) the capacity fluctuation constraint among RUs to assure the fairness of QoS for the RUs; 3) one more tier for caching is added to the proposed solution for more flexibility in video source selection control at the small-cell base station (SBS) to provide RU with maximum capacity and flexibility for video retrieval. From the proposed models, all the system models are formulated and simulated on computer with Matlab and Genetic Algorithms (GAs) to increase the processing speed while ensuring the exact or approximated optimal results of the optimization problems. Hence, the simulation results demonstrate the benefits of the proposed solutions compared to other conventional benchmarks as well as outstanding issues that need solving in the thesis.

The thesis results are a valuable reference contribution to the research community in the field of video streaming optimal control, i.e., the control of multi-tier caching and downlink resource sharing in 5G UDN to maximize capacity video streaming to device users. The scientific significance of the thesis is confirmed through research results published in one article in a prestigious national journal (Journal of Science and Technology: Issue on Information and Communications Technology), one article in the prestigious International journal with ISI index (IEEE Systems Journal, IF = 4.5), and one article presented and published at the International conference on INISCOM'20 (International Conference on Industrial Networks and Intelligent Systems).

In order to continue to improve the multicast video streaming models in 5G UDN that have been proposed to be more appropriate, the research results in the thesis will be expanded in the following directions: 1) The system will be completed. It is better to combine the model of Chapter 4 and Chapter 5. At that time, the caching selection control process is done with three-tier, the spectrum resource of SU is effectively utilized by sharing with many through a fairer QoS control strategy for better SU, the physical attributes and user social relationships are simultaneously reviewed along with the QoS fairness of the RUs; 2) Evaluate the system performance from a simple set of parameters, distributed capacity to RUs, and QoS fairness constraints for SU and RU will be improved by better set of evaluation parameters than QoE (Quality of Experience) is characterized by probability of successful video access, video waiting time from request to view, image quality of video, continuity of video playback video quality fluctuations; 3) With a more complete expansion system combined with a more complex set of QoE performance parameters, GA needs to be studied for further improvements in accuracy and execution time. In addition, it is also necessary to learn more suitable algorithms according to the current trends such as machine learning, deep learning, ... to solve the optimal problem and compare effectively with the applied GA in order to choose a good algorithm most to deploy the system.

LIST OF PUBLICATIONS

1. List of publications of Thesis

[C1] Thanh-Minh Phan, Nguyen-Son Vo, Minh-Phung Bui, Xuan-Kien Dang, and Dac-Binh Ha, "Downlink Resource Sharing and Caching Helper Selection Control Maximized Multicast Video Delivery Capacity in Dense D2D 5G Networks," *Journal of Science and Technology*, vol. 18, no. 4.2, pp. 12-20, April 2020.

[C2] Nguyen-Son Vo, **Thanh-Minh Phan**, Minh-Phung Bui, Xuan-Kien Dang, Nguyen Trung Viet, and Cheng Yin, "Social-aware Spectrum Sharing and Caching Helper Selection Strategy Optimized Multicast Video Streaming in Dense D2D 5G Networks," *IEEE Systems Journal*, pp. 1-12, June 2020.

[C3] Thanh-Minh Phan, Nguyen-Son Vo, Minh-Phung Bui, Quang-Nhat Tran, Hien M. Nguyen and Antonino Masaracchia, "Downlink Resource Sharing and Multi-tier Caching Selection Maximized Multicast Video Delivery Capacity in 5G Ultra-dense Networks", in *Proc. of EAI International Conference on Industrial Networks and Intelligent Systems (INISCOM '20),* Ha Noi, Vietnam, August 2020, pp. 19-31.

2. List of publications other

[C4] Đặng Xuân Kiên, Nguyễn Việt Chính, **Phan Thanh Minh**, "Ứng dụng mạng nơ ron tích chập lai ghép để xử lý ảnh trong hệ thống báo động trực ca hàng hải", *Tạp chí Khoa học Công nghệ Giao thông vận tải*, Số 32-05/2019, trang 47-52, 2019.

[C5] Thanh-Minh Phan and Xuan-Kien Dang, "Current Challenges in Communication and 5G Networks for Autonomous Marine Systems," in *Proc. of The 18th Asia Maritime & Fisheries Universities Forum (AMFUF2019)*, Hai Phong City, Vietnam, November 2019, pp. 138-148.

[C6] Quang-Nhat Tran, Nguyen-Son Vo, **Thanh-Minh Phan**, Minh-Phung Bui, Minh-Nghia Nguyen and Ayse Kortun, "Downlink Resource Allocation Maximized Video Delivery Capacity over Multi-hop Multi-path in Dense D2D 5G Networks", in *Proc. of The 4th International Conference on Recent Advances in Signal Processing, Telecommunications & Computing (SigTelCom2020)*, Hanoi, Vietnam, September 2020, pp. 72-76.

[C7] Quang-Nhat Tran, Nguyen-Son Vo, Quynh-Anh Nguyen, Minh-Phung Bui, **Thanh-Minh Phan**, Van-Viet Lam and Antonino Masaracchia, "D2D Multi-hop Multi-path Communications in B5G Networks: A Survey on Models, Techniques, and Applications", *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems*, vol. 7, no. 25, p. 167839, January 2021.

3. Scientific research

[D1] Phan Thanh Minh (member), "Nghiên cứu thiết kế hệ thống tự động chỉnh định và giám sát ổn định điện áp máy phát điện tàu thủy dựa trên giải thuật mờ thích nghi tương tác trên nền Matlab", *Bộ Giao thông vận tải*, Mã số DT203039, 01/2020-12/2020.