Revenue Model with Multi-Access Edge Computing for Cellular Network Architecture

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***Abstract*— Due to the drastic growth in the number of devices connected to mobile networks, the demand for further expansion of the capacity of wireless communication is increasing. It is necessary to decrease the traffic on the backhaul and reduce the end-to-end latency. To address it, in the last few years, the authors have proposed the concept of mmWave overlay heterogeneous cellular networks, where mmWave small cell base stations are introduced into the conventional macro cells. The conventional cloud applications are deployed on the Multi-access Edge Computing (MEC) according to the application requirements and data traffic situations, and the users are controlled with out-of-band C-plane to connect to the surrounding MEC applications. For the installation of MEC in the heterogeneous cellular networks, to the best of authors knowledge, there is no research conducted on whether a business model can be established when additional fees are paid for MEC. In this paper, the authors attempt to introduce a new concept of ecosystem for MEC based on the combination of ultra-broadband mmWave communications. Moreover, the authors propose a business model for MEC, and report the numerical analysis results from simulations.**

Keywords—5G, HetNet, mmWave, MEC, Backhaul, Revenue

I. Introduction

In recent years, due to the drastic growth of applications and services using mobile networks, a wide variety of connected devices have greatly increased in number. The whole data traffic in mobile networks is expected to continuously increase at an annual average growth rate of 46% and reach 77 exabytes per month by 2022 [1]. In order to deal with the heavy traffic burden on mobile networks, the millimeter-wave (mmWave) frequency band (higher than 24GHz) is adopted in 5G (the 5th Generation Mobile Networks), which achieves very high capacity [2]-[4]. At mmWave band, very high-speed data communication is possible, due to the ultrawide available bandwidth, e.g., up to 7GHz of the continuous spectrum at 60GHz unlicensed band, but it also has the disadvantage that the coverage is quite limited, due to the high path loss and high oxygen absorption. In order to take advantage of mmWave in mobile networks, the multi-band heterogeneous networks (mmWave HetNet) that use mmWave in the small cell side and sub-6GHz in the macro cell side has been proposed [5] [6]. In addition, to prevent the instantaneous disconnection by frequent handover, C/U splitting was also introduced, by which the macro cell base stations (BSs) always take charge of the control plane (C-plane). [5] has shown that a system rate gain of 1000 times can be achieved by this novel architecture.

However, even if the traffic load on the access side is improved by the mmWave communication of 5G, data traffic of each individual user grows as the development of cloud services such as video distribution services (YouTube, Netflix, etc.) and storage services (Dropbox, Google Drive, etc.). And the bottleneck could appear at the backhaul side because of the limited capacity [7] [8]. Moreover, due to installing the small cell with the higher frequencies, the coverages of the small cells are very narrowed and it is necessary to set many small cells in the macro cell. Then, it is necessary for small cells to lay a lot of backhauls link (optical fiber) depending on the number of small cells. The rates of optical fiber line penetration in most countries are still at very low levels for sufficient backhaul lines [9]. When the mmWave system is deployed under such a low backhaul capacity, the backhaul could become a bottleneck and it is impossible to expect a high system rate. In order to solve the backhaul bottleneck problem, this paper focus on Multi-Access Edge Computing (MEC) [10]-[13], which makes it possible to provide end-to-end (E2E) low latency from user to MEC server, traffic reduction to backhaul networks, high-speed download and so on.

In our previous work, we have studied the system level simulator of mmWave HetNet developed in [5]. We made a further step by extending and evaluating the combined effect of mmWave access and MEC in the case of limited backhaul capacity and a prefetching algorithm was also proposed [14]. However, in order to deploy MEC on the cellular side, to the best of authors' knowledge, there is no research conducted on the business model, which evaluates whether extra expense would be paid for the deployment of MEC, or additional revenues would be obtained. In this paper, we propose a business model and an ecosystem for MEC, and report the numerical analysis results by simulations.

This paper is organized as follows. Sect. II explains the network architecture of the ecosystem with mobility model, traffic model and E2E latency model including communication and computation resource. Sect. III proposes a business model for MEC. The analysis result of the proposed model is shown in Sect. IV. Finally, Sect. V concludes this paper.

II. System Architecture Model

The proposed ecosystem is the local ecosystem in which the applications and services can be conducted through local communication with MEC instead of the center server in the cloud. This section describes its model including network architecture, user mobility model with hotspot, traffic model and E2E latency model.

A. *Network Model*

The configuration of the proposed ecosystem architecture is shown in Fig.1. This configuration is divided into a mobile operator holding the fronthaul side (access side), a backhaul owner holding an optical fiber that can be loaned to other operators, i.e., a dark fiber, a cloud owner and third party. In the fronthaul side, we consider the HetNet structure, where mmWave small cells are deployed in the conventional macro cells, is interfered by 6 surrounding macro cells. We assume that the network architecture model proposed in [15], where the macro cell is 3GPP (Third Generation Partnership Project) RAN (Radio Access Network) and the small cell is non-3GPP.

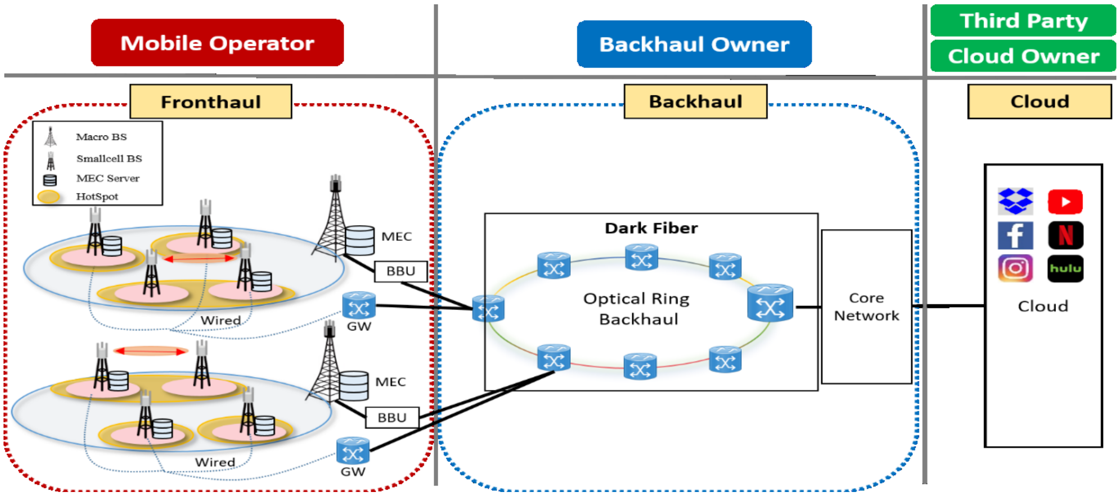

Fig.1. Network Model

Multiple small cells are deployed for covering a wide area of traffic concentration area, i.e., hotspot. The small cell has 3-sector mmWave access and 3-sector backhaul link, and any of small cells in hotspot has a wired backhaul link and MEC server. The utilized protocol and frequency band are the same as in [14], and the protocol of small cells is based on the IEEE 802.11ad standard [16]. The frequency band proposed in the standard has 4 sub-channels of 2.16GHz bandwidth in the 57-66GHz band. In this paper, we only leverage one of 4 sub-channels for 3-sector on the access side. In each sector, the transmit signal from small cell is directed to the desired user by beamforming using massive antennas equipped in small cell BSs.

Application services such as 4K/8K streaming distribution, connected car, etc., which produce a large amount of data operating on the MEC are provided. If there is no MEC in connected small cell, users receive application services of MEC in adjacent small cell via a mmWave backhaul. In this paper, the resource allocation of MEC is performed that the application service migration simultaneously another MEC based on the context information of the user location [14].

B. *Mobility Model among Hotspots*

Firstly, we explain the deployment of user. The number of user h_u in each hotspot is decided as below:

$$h_u = \frac{\alpha N_U}{h_n} \tag{1}$$

where α is the ratio of the number of user in hotspots to the total number of users, N_U is the total number of user, h_n is the number of hotspots in one macro cell. Before the users are deployed, the user is determined the location of the macro or hotspot. Next, coordinate positions within the placement location are determined based on the uniform distribution. As show in Fig.2, all users are deployed inside or outside hotspots in macro cell.

Next, we describe the mobility model among hotspots. This proposed model is developed in [14]. There are various types of hotspots, and the probability distribution to be selected as the destination varies depending on the type. The destination of the user is determined using the Markov chain model [17]. We set two types and set the probability distribution is fixed. As shown in Fig.2, the red circles indicate a temporary stay place such as a station, and the blue circles indicate a long stay place such as a shopping mall. The probability of destination hotspot is set to the value depending on the role of hotspot and distance to the user's stay place in Fig.3. In addition, we define the probability of mobility destination matrix **A** is defined as follows:

$$\mathbf{A} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1N} \\ p_{21} & p_{22} & & p_{2N} \\ \vdots & & \vdots & \vdots \\ p_{N1} & p_{N2} & \cdots & p_{NN} \end{bmatrix} \tag{2}$$

where N is the number of the hotspot, and $p_{i,j}$ represents the probability of mobility destination from the user's location hotspot i to the destination hotspot j.

The user mobility algorithm is as follows:

1. The user selects the destination based on the probability distribution matrix **A** depending on the deployment place.
2. The user moves at a constant speed to the destination on the shortest route and stays there for a certain time.
3. After staying time, the user selects the destination based on matrix **A** for next destination again and again.

These three steps are repeated by the end of the evaluation time. One user mobility in simulation is shown in Fig. 4. The initial position of user is shown in the green circle, and the final position is pointed by the red square. In this example, the total number of destinations is two during the evaluation time. Moreover, the user's movement path is shown in the blue line. Table I shows the parameter of the proposed mobility model.

C. *Traffic Model*

Since the user traffic model have been presented in [14] [18], we only give a brief explanation about it. Essentially, this model is based on user traffic data measured in Shibuya in 2012. By fitting the gamma distribution of this model, a highly accurate traffic distribution could be created.

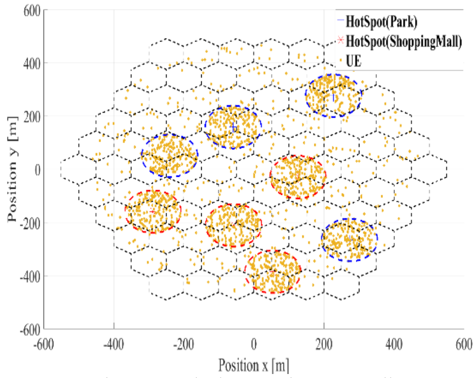

Fig.2. User deployment in macro cell

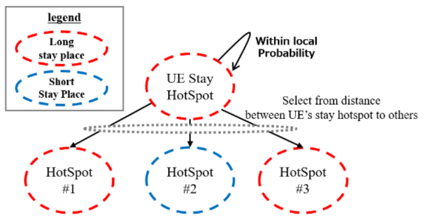

Fig.3. Destination Probability using Markov chain model

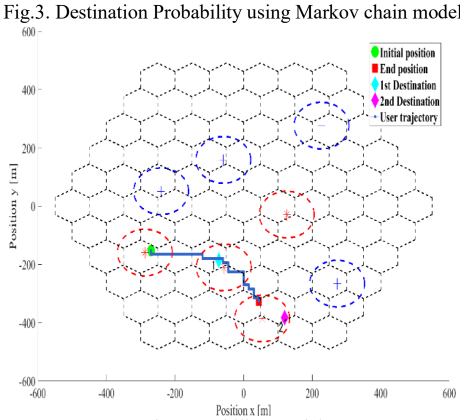

Fig.4. Mobility Model

Moreover, in the future, the shape parameter will not change and average traffic value could be controlled by the scale parameter. This paper assumes that traffic has increased by 1000 times in 2020 since the traffic data was measured in 2012 because it is increasing twice exponentially. As shown in Fig.5, traffic data were created by this model and QoS Class Identifier (QCI) defined in LTE (Long Term Evolution) [19] was mapped to it. And the average generation interval of average traffic packet is 8 seconds based on exponential distribution. It is assumed that the traffic data quantity depends on the user movement status, the small traffic data is sent to the macro cell while the user is moving, and the large traffic data is sent to the small cell side when the user is stationary at the hotspot.

D. *E2E Latency Model*

Many low latency services can be utilized with MEC such as automated driving, Augmented Reality conference, and streaming 4K/8K media [20] [21]. From the end user viewpoint, it is necessary to consider not only the latency in the wireless layer, but also the total latency called E2E latency. So far, various approaches have been studied for the E2E delay [13] [22] [23]. [13] dealt with an optimization problem that minimizes the total power consumption subject to E2E latency. In [22], the proposal of the algorithm including the delay of the queuing theory was implemented. [23] proposed delay control by task scheduling.

TABLE I. PARAMETER OF MOBILITY MODEL

Parameter	Value
User Speed	3 m/s
Road Interval	10 m
Staying Time	30 s

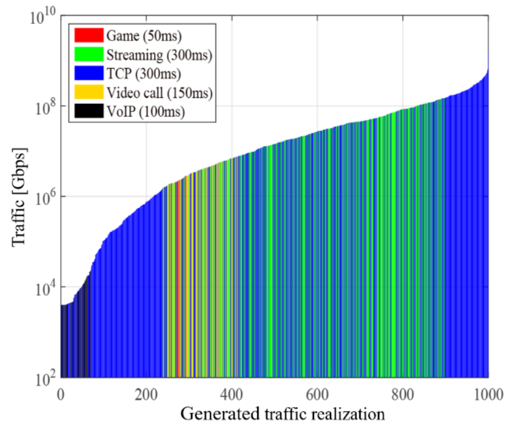

Fig.5. Traffic Model [17]

TABLE II. PARAMETER OF HOP COUNT TIME [25]

Parameter	Value
MSS	1460
$W_{\max}$	300
p_{loss}	0

In this paper, the E2E latency model consists of four contributions based on [13] : i) the time $T_{k,i}^{\text{tx}}$ represents the user equipment (UE) k sends the all bit b_k to the small cell i; ii) the time $T_{i,j}^{\text{hop}}$ represents the number of hop count time from the small cell i to the MEC server j; iii) the execution time $T_{j,k}^{\text{exe}}$ indicates the processing time of CPU cycle w_k running application on server computing resource f_k deployed from MEC server j; iv) $T_{i,k}^{\text{rx}}$ represents the time of the result back to the UE k from the small cell i. These formula are defined as:

$$T_{k,j} = T_{k,i}^{\text{tx}} + T_{i,j}^{\text{hop}} + T_{j,k}^{\text{exe}} + T_{i,k}^{\text{rx}} \tag{3}$$

i) The time $T_{k,i}^{tx}$ is given by

$$T_{k,i}^{\text{tx}} = \frac{b_k}{B_i C_{k,i}} \tag{4}$$

where B_i is the available bandwidth for small cell i, $C_{u,i}$ in bps/Hz is link capacity of UE k from the small cell i based on signal-to-interference-noise ratio (SINR) [18]. ii) the time $T_{i,j}^{hop}$ based on the empirical model of TCP in [24] is given by

$$T_{k,i}^{\text{tx}} = \left[\log_{1.57} N + f(p_{\text{loss}}, \text{RTT})N + 4p_{\text{loss}} \log_{1.57} N + 20p_{\text{loss}} + \frac{(10 + 3\text{RTT})}{4(1 - p_{loss})W_{max}\sqrt{W_{max}}}\right]\text{RTT}/2 \quad (5)$$

$$f(p_{\text{loss}}, \text{RTT}) = \frac{2.32(2p_{\text{loss}} + 4p_{\text{loss}}^2 + 16p_{\text{loss}}^3)}{(1 + \text{RTT})^3}N + \frac{1 + p_{\text{loss}}}{\text{RTT}10^3}$$

where N denotes the number of packets ($=\frac{bit_k/8}{MSS}$), p_{loss} is the packet loss, $W_{\max}$ is the maximum size of the congestion window, MSS is the maximum segment size. Table II shows the parameters given in Eq. (5) based on [25]. iii) $T_{j,k}^{\text{exe}} = w_k/f_k$ is execution time at MEC server. $T_{i,k}^{\text{rx}}$ typically only accounts for a negligible partition of the overall latency, and thus it is assumed to be a fixed value.

III. Optimal Algorithm

In this paper, we propose an ecosystem model with joint optimization of deployment of small cell and revenue model.

A. *Optimization of Small Cell Deployment Placement*

In this paper, it is assumed that the MEC server is placed on the small cell side, and MEC service could be used only in hotspot side. In this case, it is necessary to design of small cell to maximize throughput on access side when small cells are deployed on the hotspot. Hence, the proposal method explains about the small cell deployment on hotspot under the environment where a hotspot is larger than a small cell coverage. The optimization of small cell deployment placement algorithm is as follows:

1. The mobile operator determines candidates for small cell location in macro cell.
2. Propagation channel at the determined placement of candidate is measured by the simulation.
3. If optimization of candidate search is for all deployment candidate, the amount of calculation becomes enormous. Therefore, only the place where the hotspot is covering the candidate destinations is extracted.
4. Optimization of maximize the mean user throughput in hotspot can be described as:

$$\max f_{\text{tr}}^{\text{mean}}(N_{SC}) = \frac{1}{N_{UE}}\left[\sum_{i \in N_{UE}} \sum_{j \in N_{SC}} \text{SINR}_{i,j}\right] \quad (6)$$

$$\text{SINR}_{i,j} = \log\left(1 + \frac{T_x |h_{i,j}|^2}{n_{noise} + T_x \sum_{u \in N_{SC}, u \neq j} |h_{i,u}|^2}\right)$$

   where N_{UE} is the number of UE, N_{SC} is the number of candidate for small cell, T_x denotes transmission power from small cell, $h_{i,j}$ is propagation channel from UE i to small cell j and n_{noise} is defined as noise power.

5. Finally, as shown in Fig.6, we deploy the small cell on covering hotspot based on the optimization formula in Eq. (6) in the number of small cell.

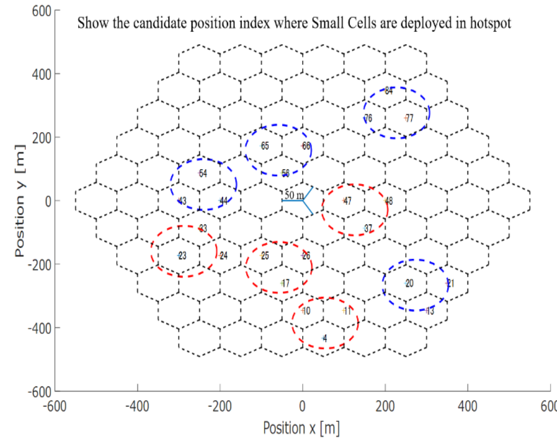

Fig.6. Optimal Small Cell deployment selection

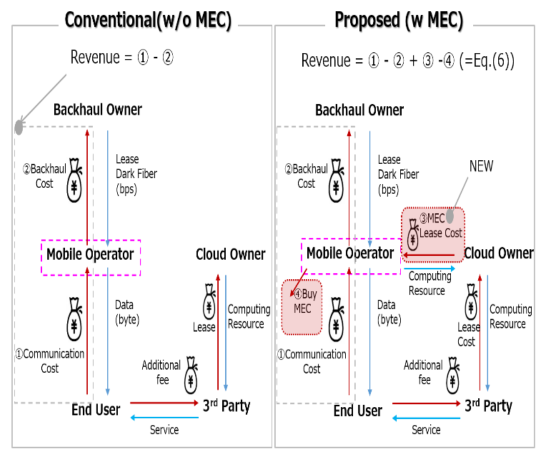

Fig.7. Revenue Model on MEC

TABLE III. Parameter of Simulation

Parameter	Value
Bandwidth (Macro/Small)	10 MHz / 2.16 GHz
Carrier freq. (Macro/Small)	2.1 GHz / 60 GHz
Number of UE	2,000
Number of BS (Macro/Candidate Small/Hotspot)	1 / 91 / 8
Number of BS sectors (Macro/Small)	3 / 3
Antenna height (Macro/Small/UE)	25 m / 4 m / 1.5 m
Tx power (Macro/Small)	46 dBm / 10dBm
Radius (Macro/Small/Hotspot)	500 m / 50 m / 80 m
Channel Model[26]	QuaDRiGa Channel Model
Flat-rate communication fee[27]	40$
Backhaul cost[28]	30$
MEC server cost/unit[29]	600$
MEC resource cost	0.01$/0.5kB-0.01$/5kB

In this paper, we search through the whole state space of N_{SC} to derive the optimum number of small cells in the target macro cell.

B. *Optimization of Revenue with Mobile Operator*

So far, cloud services have become mainstream, but a different behavior from the conventional business model will appear with the development of MEC. At the same time, Mobile Virtual Network Operators (MVNOs), which offer mobile internet access services without any facilities, have been participating in the market where mobile carriers were monopolized until now. Based on these, it is assumed that a mobile operator who possesses only the fronthaul and MEC in Fig.1 will appear. In this paper, we propose a novel revenue model with MEC, which is shown in Fig.7. In the both models, players are divided into end users, mobile operator, backhaul owner, cloud owner and third party. In the conventional model, the mobile operator allows end user unlimitedly communication instead of paying flat-rate communication fees from end users. The backhaul cost is paid to the backhaul owner in accordance with the user's traffic volume. Meanwhile, the end user pays for the application service to the third party and receives the service. Third party pays resources to cloud operator to deploy their services. In the proposed model with MEC, the money flow of mobile operator is changed compared to the conventional way, and the mobile operator buys MEC server and leases MEC resources to cloud operator. Cloud operator is an orchestrator and operates the application in the MEC server for the leased resources because cloud operator has the knowledge and technology in cloud services. Therefore, the revenue cost problem for mobile operator can be formulated as:

$$\max f_{\mathrm{RV}}(N_{MEC}) = C_A N_{UE} + \sum_{i \in N_{UE}^{MEC}} \sum_{j \in N_{MEC}} C_{MEC}^{RS} w_{i,j} \quad (7)$$

$$-C_{MEC} N_{MEC} - C_B \left(\sum_{i \in N_{UE}} D_i - \sum_{i \in N_{UE}^{MEC}} \sum_{j \in N_{MEC}} D_{i,j} \right)$$

subject to the following condition

$$\sum_{i \in N_{UE}^{MEC}} \sum_{j \in N_{MEC}} w_{i,j} \le f_S N_{MEC}$$

$$\sum_{i \in N_{UE}^{MEC}} \sum_{j \in N_{MEC}} D_{i,j} \le \sum_{i \in N_{UE}} D_i$$

$$0 \le N_{MEC}$$

$$w_{i,j} = D_{i,j}$$

where the optimization problem attempts to maximize the revenue between the demanded traffic and the number of MEC server N_{MEC}. C_A denotes the flat-rate communication fee, C_{MEC}^{RS} is the lent MEC resource cost, C_{MEC} is MEC server cost, C_B is the backhaul cost, N_{MEC} is the number of MEC server, $w_{i,j}$ denotes the MEC resource used by user *i* at MEC server *j*, D_i is the demanded traffic from user *i*, N_{UE}^{MEC} denotes the number of UE using MEC server. $D_{i,j}$ denotes the demanded traffic sent from the user *i* to MEC server *j*. f_S is the total MEC resource cost.

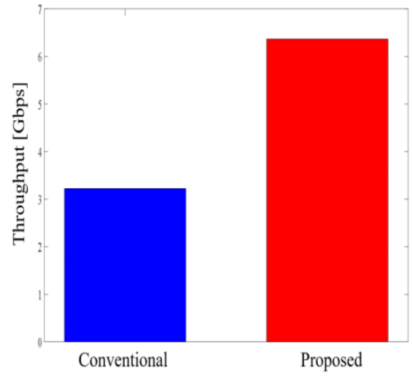

Fig.8. Result of Throughput Improvement

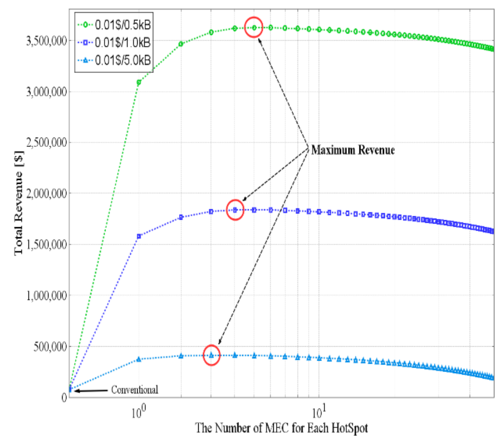

Fig.9. Revenue optimization when varying MEC resource cost

IV. System Simulation

We analyze the effectiveness of the two revenue models for MEC i.e. whether additional funds would be paid for the deployment of MEC, or additional revenues would be got in Fig.8. To verify the revenue for the mobile operator, we vary the number of MEC to confirm the revenue maximization formula in Eq. (7). Table III summarizes the simulation parameters. We set one macro cell, 91 candidate small cells and 8 hotspots. The maximal number of MEC in each hotspot is 15 and the revenue is maximized against the number of MEC. For the fronthaul side, the parameters of macro cells and small cells are based on 3GPP and IEEE802.11ad. The flat-rate communication fee is set as C_A = 40 \$ [27]. For the backhaul side, the backhaul cost C_B is 30 \$ [28]. The MEC server per unit is assumed to hold 1 GHz cycle, and its price is 600 \$ [29]. The MEC resource cost is in the range of 0.01 \$/0.5 kB to 0.01 \$/5.0 kB.

Figure 8 shows the optimization result for maximizing the system's mean throughput in Eq. (6). Compared to the conventional scheme without optimizing where small cells are deployed to fully cover the hotspot, the proposed scheme improves the throughput about 3.0Gbps. Such throughput improvement is owing to the improvement of SINR beneficial from the proposed method which helps UE to connect to a small cell with the highest signal-to-noise ratio (SNR) while concurrently alleviate interferences from other small cells. By improving the throughput on the access side, mobile operators can provide end users with high-capacity services using MEC.

Moreover, we analyze the revenue model with MEC when the above optimization method is applied. Figure 9 shows the analysis result of the revenue for mobile operator where the horizontal axis shows the number of MEC deployed in each hotspot and the vertical axis shows the achieved revenue. As shown in Fig.9, it can be seen that the total revenue is increased by increasing the MEC resource cost, up to a certain point. Firstly, revenue is tending to increase against the number of MEC deployed owing to the edge signal processing and the reduction of traffic burden over the backhaul side. However, the revenue starts to saturate and then decrease since sufficient MEC resources are capable of processing all traffic on the access side. The revenue is then decreased due to excessive capital investment of MEC servers.

Moreover, we also see the tendency of the revenue maxima shift to the right as the cost for MEC resource increases.

V. Conclusion

In this paper, we proposed a business model and an ecosystem for MEC, and analyze the optimization of small cell deployment and revenue model with MEC by simulations. As a result, the throughput in hotspot could be significantly improved. Moreover, with regard to revenue, it was found that the profit and loss tended to increase with the addition of MECs, and it was found that the number of MEC that could make the most profit is about 4 when the MEC resource cost is 0.01 $/1.0 kB.

Our future work is designing a more sophisticated business model with an ecosystem of cellular architecture with MEC. In addition, we also plan to develop how to improve the satisfaction of all users and design a reasonable algorithm.

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