Resources Management in Virtualized Information Centric Wireless Network

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***Abstract*—Information-Centric Networking (ICN) and Wireless Network Virtualization (WNV) are two emerging technologies for the next-generation network infrastructure. ICN provides the key technology to reduce the network traffic by caching the contents temporarily and aggregating the same content requests. WNV enables the resources sharing among Infrastructure Providers (InPs) and Mobile Virtual Network Operators (MVNOs), to reduce capital expenditures and operating expenses. Also, the network resource management becomes easier because of WNV. In this paper, we combine these two technologies to improve the performance of the network and the profit of the MVNOs. We formulate the optimization problem to solve the cache allocation problem and maximize the profit of MVNOs by controlling the usage of cache space, backhaul link, and radio resources. Finally, we validate our proposed scheme using a chunk-level simulator. The simulation results show that the proposed mechanism can improve the profit of MVNOs and user's QoS.**

***Index Terms*—Information Centric Networking, Wireless Network Virtualization, In-Network Caching, Resource allocation.**

I. Introduction

Information-Centric Networking (ICN) [1] [2] and Wireless Network Virtualization (WNV) [3-6] are the most promising technologies to build the next-generation network. ICN introduces in-network caching and name-based packet forwarding or routing. So, ICN-enabled nodes temporarily store the contents in their cache space to provide the users who request the same contents. Also, the ICN-enabled nodes aggregate the same content request. Thus, each node only forwards the first content request to the original server or to the temporary content source, while the latter requests for the same content are waiting at the node for the returned content. Therefore, by employing ICN in the network not only reduces the network traffic but also improves the users Quality of Service (QoS).

WNV introduces the resources (such as wireless radio access networks (RANs), core networks (CNs) and etc...) sharing mechanism, among Infrastructure Providers (InPs) and Mobile Virtual Network Operators (MVNOs), to reduce the capital expenditures (CapEx) and operation expenses (OpEx). Moreover, WNV helps InPs to gain more revenue from leasing the virtualized resources to the MVNOs with the wholesale price, instead of getting revenue only from the registered users. In addition, WNV improves the network management of future heterogeneous wireless network to be easier.

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A. Related works

The combination of information-centric networking with the wireless network virtualization is introduced in [3] [4]. The wireless network virtualization is widely discussed in [5], and the usage of wireless network virtualization in 5G mobile network is discussed in [6] which used ADMM to solve the resource allocation problem. Two types of wireless virtualization schemes are presented in [7]. 1) The InP directly manages the resources allocation of the users of MVNO. 2) The hierarchical resource allocation, where InPs allocate the resources to the MVNOs, and MVNOs allocate their virtual resources to their users. In the hierarchical resource allocation, we can categorize into three types of resource sharing or isolation scheme: fixed sharing, dynamic sharing, and hybrid sharing. In the fixed sharing scheme, InPs do not allow overuse of their resources to the MVNOs. In the dynamic sharing scheme, there is no restriction on the resource usage and the InPs grantee the certain pre-determined requirements to the MVNOs. In the hybrid scheme, InPs initially give the certain amounts of resources to the each MVNO, according to the pre-determined service agreements. Then, the InPs share the leftover resources to the MVNOs through the auctions mechanism or etc..

B. Challenges of combining the ICN and WVN to build a better network

Cache space management becomes the main issue because different MVNOs have different interests to cache the contents and they use the same physical cache space of each Base Station (BS) or Small Cell Base Station (SBS). Thus, the physical cache space of each BS should be logically partitioned into virtual cache spaces. In this case, virtual cache spaces allocation becomes another emerging issue, where these cache spaces should be fairly or efficiently allocated among different MVNOs. The cache extension decision, whether to buy or stop buying the extra virtual cache space is also import to improve the profit of the MVNOs.

C. Our Contributions

Our contributions can be summarized as follow.

- We propose an information-centric wireless network virtualization framework. We apply the hierarchical business model for resource allocation and hybrid model for the physical resources sharing.
- We formulate the virtual resource allocation and in-network caching strategy as an optimization problem, which maximizes the profit of MVNOs and improves the user's QoS.
- We have evaluated our proposed scheme using the chunk-level simulator.

The rest of the paper is organized as follow. Section II discusses the system model. The proposed scheme is evaluated in section V. Finally we conclude in section VI.

II. System Model

The system model is categorized into three categorizes: 1) business model, 2) network model and 3) cost model.

A. Business Model

In this paper, we adopt the hierarchical business model which is shown in Fig. 1 and it includes three parties: InPs, MVNOs, and users. In this business model, **InPs** lease the physical substrate infrastructure (e.g. radio resources, storage capacity resources, core network, and radio access network, etc.) with the wholesale price to the MVNOs who do not have the physical network infrastructure. Then, **MVNOs** resell the virtual resources to their users. The **users** can be classified into two groups: 1) the users subscribe the services from the InPs, and 2) the users only subscribe the services from the MVNOs. In this proposal, we only consider the second type of users.

The charging process among InPs, MVNOs, and users are as follows. Initially, MVNOs buy the resources from the InPs with the fixed price only for limited resources. Also, InPs have the reserve resources for their users. If the MVNOs want to buy extra resources, MVNOs can request to the InPs. In this case, the InPs will charge with the dynamic price to the MVNOs for using these resources. Then, MVNOs sell the virtual resource slices to the users with fixed price.

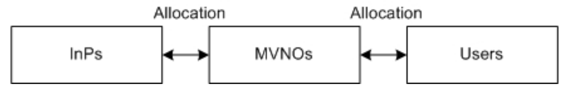

Fig. 1. Business Model

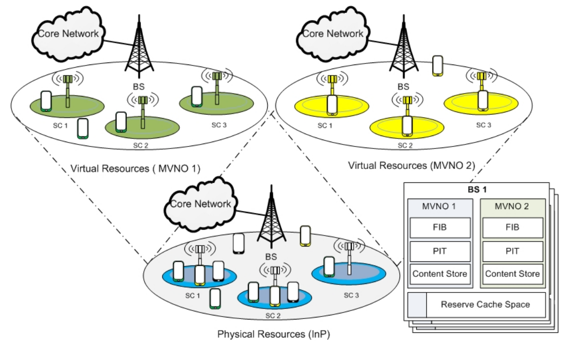

Fig. 2. Network Model

B. Network Model

The network model is shown in Fig. 2, where the BSs and SBSs are attached with the cache space to store the content and also connected to the content server via the backhaul link. For the simplicity, we define the BSs and SBSs of the InP$_p$ as BS$_j^p$, where $p = 1, ..., P$ and $j = 1, ..., J$. The coverage radius of BS$_j^p$ is denoted as BR$_j^p$. The backhaul capacity of BS$_j^p$ is B_j^p bps. All of the unsatisfied requests at the BS$_j^p$ can be provided by the server. BS_j^p own the N_j^p channels, and W_j^p Hz is the spectrum bandwidth of BS_j^p. The transmitted power of BS_j^p is P_j^p watt per Hz. The MVNO$_i$'users, those are connected with the BS_j^p are denoted as $u_{ij}^p \in U$. $a_{u_{ij}^p}$ is the user association indicator, where $a_{u_{ij}^p} = 1$ means that user u_i associates to BS_j^p, otherwise $a_{u_{ij}^p} = 0$. The physical cache capacity of the BS$_j^p$ is denoted as $Z_j^p \in Z$. The virtual cache space of MVNO$_i$ at the BS$_j^p$ is denoted as x_{ij}^p. The leftover cache space of the BS$_j^p$ is denoted as ρ_{ij}^p, where $\rho_{ij}^p = Z_j^p - \sum_{i \in I, u_i \in U_i} z_{ij}^p$. There are total number of file F, where $F = 1, 2, .., f$.

MVNO$_i$ manages their own virtual cache space instead of managing by the InPs, which prevents the replacing of important contents of one MVNO by others. So, each MVNO$_i$ can use their own cache replacement policy. We limit the MVNO$_i$ owned cache space at the BS_j^p, $\sum_{f=1}^{F} \sum_{k=1}^{K} x_{f_k ij}^p \leq z_{ij}^p$, where $x_{ijf}^p s_f$ is the binary variable and s_f is the size of the content f. The MVNO$_i$ store the content f when $x_{f_k ij}^p = 1$, otherwise $x_{f_k ij}^p = 0$. MVNO$_i$ can extend their virtual cache space by buying extra cache space from InPs. Then, we define the virtual resources slice or "slice", where each slice includes the resources S:={BS/SBS, W_j^p, B_j^p} to provide one chunk to the user.

C. Cost Model

In this section, we first define the resource usage price paid by MVNOs to InPs. The radio resources usage price is $\delta_{ij}^{p,radio}$ unit per chunk. The back-haul usage price at BS_j^p is $\delta_{ij}^{p,bn}$ unit per chunk. The cache space usage price is $\delta_{ij}^{p,cache}$ per GB. The cost to retrieve one chunk (paid by MVNOs to InPs) is defined as

$$c_{f_k ij} = (x_{f_k ij}^p \delta_{ij}^{p,radio} + (1 - x_{f_k ij}^p) \delta_{ij}^p), \tag{1}$$

where x is the binary variable. If the $x = 1$, the requested chunk is already cached at the BS$_{ij}^p$, otherwise $x = 0$. So, the total cost to retrieve the contents for all user at the BS$_{ij}^p$ becomes,

$$\sum_{u=1}^{U} \sum_{f=1}^{F} \sum_{k=1}^{K} a_{u_{ij}^p} u_{f_k ij}^p c_{f_k ij}, \tag{2}$$

where $a_{u_{ij}^p}$ is the user association parameter, $u_{f_k ij}^p$ is the content request parameter. If $u_{f_k ij}^p = 1$ the chunk k of content f is requested by user u, otherwise $u_{f_k ij}^p = 0$. Thus the total cost paid by MVNO$_i$ at the BSj to InPs or investment of MVNO$_i$ at the BSj becomes,

$$v_{ij}^p = \sum_{u=1}^{U} \sum_{f=1}^{F} \sum_{k=1}^{K} a_{u_{ij}^p} u_{f_k ij}^p c_{f_k ij} + \delta_{ij}^{p,cache}, \quad (3)$$

The cost to retrieve one chunk (paid by users to MVNOs) is defined as $a_{u_{ij}^p} u_{f_k ij}^p l_{f_k ij}$, where $l_{f_k ij}$ is the selling price to user u. So, the revenue of MVNO$_i$ at BS$_{ij}^p$ becomes,

$$d_{ij}^p = \sum_{u=1}^{U} \sum_{f=1}^{F} \sum_{k=1}^{K} a_{u_{ij}^p} u_{f_k ij}^p l_{f_k ij}. \quad (4)$$

The net profit for MVNO$_i$ at each BSj^p becomes

$$e_{ij}^p = d_{ij}^p - v_{ij}^p. \quad (5)$$

III. Problem Formulation

In this section, we formulate the optimization problem to maximize the profit of the MVNO$_i$ at the each BS$_j$. In the optimization problem 6, the objective function is the profit of each MVNO at BS$_{ij}^p$. The first constraint granted one user can connect with only one BS. The second constraint is related to radio resources, where $w_{u_{ij}}$ is in the range of 0 to 1. The third constraint is related with the backhaul capacity limit, and the fourth is the cache capacity constraint. The fifth constraint is related with cache hit ratio $\varphi_{ij}^p(t) = h_{ij}^p(t)/(h_{ij}^p(t) + m_{ij}^p(t))$, where $h_{ij}^p(t)$ is the total number of cache hit, and the $m_{ij}^p(t)$ is the total number of cache miss for the MVNO i at the BS$_j$.

$$\begin{aligned}
\underset{x_{f_k ij}^p, a_{u_{ij}}}{\text{maximize}} \quad & e_{ij}^p \\
\text{subject to} \quad & \sum_{j}^{J} a_{u_{ij}^p} = 1, \forall i, j \\
& \sum_{u_i}^{U_i} a_{u_{ij}^p} w_{u_{ij}^p} \leq 1, \forall i, j \\
& \sum_{u_i}^{U_i} R_{u_{ij}^p} \leq B_j, \forall i, j \\
& \sum_{f=1}^{F} \sum_{k=1}^{K} x_{f_k ij}^p \leq z_{ij}^p, \forall i, j \\
& \varphi_{ij}^p \leq \nu_{ij}^p, \forall i, j \\
& 0 \leq x_{f_k ij}^p \leq 1, 0 \leq a_{u_{ij}} \leq 1, 0 \leq w_{u_{ij}^p} \leq 1,
\end{aligned} \quad (6)$$

IV. Distributed profit maximization algorithm

In this section, we discuss the Algorithm 1 which distributively maximize the profit of MVNO$_i$ at the each BS$_j^p$. Every round, the algorithm store the most popular contents and monitor the net profit and hit rate. In the simulation, we set 0.5 as a hit rate threshold ν_{ij}^p.

Algorithm 1 Distributed Profit Maximization

Initially BS$_{ij}^p$ randomly stores the contents
Every time t, run the optimization problem at BS$_{ij}^p$ (6)
Sort the contents depend on number of request
Store or replace the cached contents with most popular contents from the sorted list until the cache is full
When the profit value is stable, check whether the cache hit threshold is satisfy
if the Threshold is not satisfy **then**
    Request the extra cache space to InP$_p$
end if
if InP$_p$ agrees **then**
    Buy the extra cache space
end if

TABLE I
Parameters used in the experiments

Parameters	Symbol	Value
Chunk size	a	10KB
No. of repos	$\|r\|$	1
Inter arrival rate	λ	[5,10]s
Zipf exponent	α	0.5 to 1
Catalog size	F	10^8
Total Cache size	S	5% of object size
Cache decision	DS	LCE, vicwn
Cache replacement	RS	LRU, vicwn

V. Performance Evaluation

In this section, we evaluate the performance of the proposed scheme using the chunk-level simulator, which is developed by using python. In this experiment, there are one Macro BS and two SBSs. The SBs are located within the range of the Macro BS. For the catalog size, we choose YouTube like video content, which has an approximate catalog size of about 10^8 [9] [10] [11]. Considerations of the cache size for the routers are well discussed in [10]. We assign 5% for a network cache. To generate user requests, we first consider object popularity. In this paper, the object popularity follows the Zipf distribution, which equals $P(i) = \frac{1/i^\alpha}{\sum_{j=1}^{|F|} 1/j^\alpha}$, where i is the rank of the i-th object. To run the simulation, we consider the object popularity to follow a Zipf distribution range (α = 0.5 to 1). Therefore, users request content with those popularity distributions. Arrival of requests follows the Poisson process, $P\{N(t) = n\} = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$. The parameters used in the experiments are shown in I.

A. Simulation Results

In this section, we discuss the results from simulation. We compared the proposed algorithm with the popular scheme, which used cache decision as Leave Copy Everywhere (LCE)/cache all and cache replacement policy as Least Recently Used (LRU).

1) Average Delay: Fig. 3 shows the results of an average delay to retrieve one chunk. The lower delay means the better performance. In this figure, our proposed scheme vicwn outperform than the cache all/LRU scheme, because our scheme stored popular contents and provide these contents to the users.

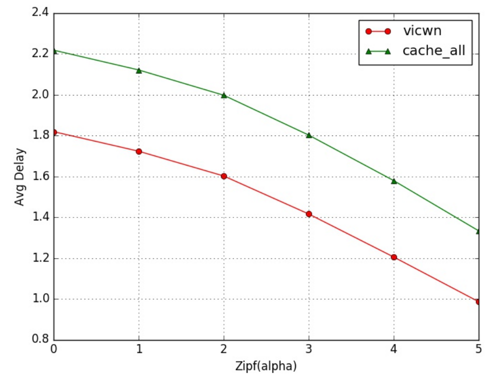

Fig. 3. Average delay comparison between the proposed scheme and LCE-LRU.

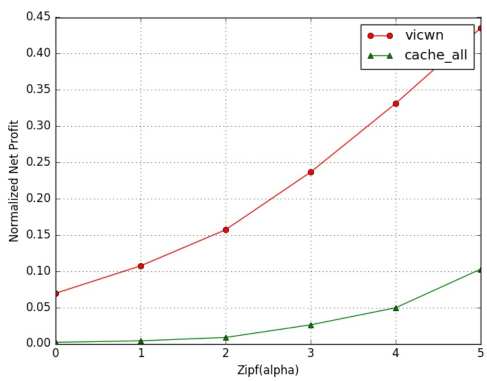

Fig. 4. Net profit comparison between the proposed scheme and LCE-LRU.

2) Net profit: Fig. 4 shows the results of MVNO's net profit, which shows the benefit of deploying cache space at BSs or SBSs can give more benefit. Higher the profit means the better the performance. In order to compare two different scenarios, we normalized the results of the net profit. In this figure, our proposed scheme vicwn outperform than the cache all/LRU scheme, because our scheme improves the profit by playing the cache space size of each BS and SBS. Also, the profit of the MVNO is directly related to the cache decision policy.

3) Backhaul usage cost: Fig. 5 shows the results of backhaul usage, where we measure the backhaul usage by the unit cost. Lower backhaul usage cost means better performance and it also reflects the profit of the MVNO. The results of our proposed scheme have lower backhaul usage cost than LCE-LRU and these results are closely related to the caching policy.

VI. Conclusion

In this paper, we proposed a next-generation network architecture which is the combination of the advantages of the ICN and WNV. We try to maximize the profit of the MVNO and improve the user's QoS. The physical cache space is divided into several logical parts for each MNVO, where MVNO can manage their own cache space, in order to improve the profit. We intensively simulated the proposed mechanism, and the experimental results show that with our proposed mechanism can improve the benefit of the MVNO without affecting of the user's QoS. For the future work, we will analysis the information-centric wireless virtualization network with different cache decision algorithm.

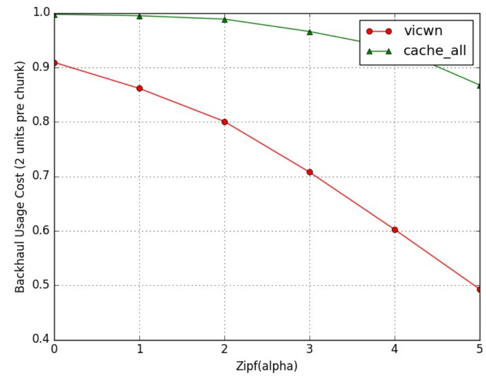

Fig. 5. Backhaul usage cost comparison between the proposed scheme and LCE-LRU.

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