A Softwarized Paradigm for Mobile Virtual Networks: Overcoming a Lack of Access Infrastructure

Nhu-Ngoc Dao, Umar Sa'ad, Viet Cuong Vu, Quang Dieu Tran, Eun-Seok Ryu, Sungrae Cho

***Abstract*—Market analysis reports suggest that the mobile virtual network operator (MVNO) market will experience subscriber growth at a compound annual growth rate (CAGR) of 10.7% from 2014 to 2020. This comes with great opportunities as well as many challenges. The major issue lies in the MVNOs' lack of spectrum allocation and an end-to-end network infrastructure, which means they must rely on mobile network operators (MNO) for wireless access network connectivity in order to serve their customers. In this article, we propose an approach that provides alternative wireless access methods to enable MVNOs to minimize their dependency on MNO networks. This leverages the fifth-generation (5G) softwarization technologies to provide selective multipath device-to-infrastructure (D2I) connections and service assortments. Supervised by software defined networking (SDN)-based edge controllers, the multi-path D2I connections provide flexible user data delivery over available communication resources without strict consideration of the MNO's infrastructure restraints. Additionally, a priority-based classification policy is applied to user data providing service assortments before it reaches the network infrastructure. Multiple pilot scenarios are implemented to verify the feasibility and performance trade-off between communication metrics of the proposed approach.**

***Index Terms*—device-to-infrastructure, software defined networking, mobile virtual network, communication management.**

I. INTRODUCTION

In recent years, a new group of mobile service providers known as mobile virtual network operators (MVNO) has emerged to provide differentiated services to customers in niche markets such as in-vehicle infotainment, retail, and roaming services [1]. These operators have neither spectrum allocation nor complete mobile network resources, especially access infrastructures. Therefore, they usually depend on the wireless communication infrastructure provided by mobile network operators (MNOs) in order to serve their customers. As a result, this dependency on MNOs limits their ability to introduce innovative services in a timely manner.

Additionally, some MVNOs primarily focus on marketing and sales or cooperating with mobile virtual network enablers and aggregators (jointly referred to as MVNE throughout the rest of this article) to reduce capital expenditure (CAPEX) for revenue maximization. Fig. 1 shows a comparison of full MVNO, light MVNO, and MVNE with respect to MNO. The MNOs own and provide end-to-end wireless communication infrastructure and services, including radio spectrum allocation, wireless access and backhaul infrastructure, and billing and customer services. Conversely, the full MVNOs provide all services except the wireless network infrastructure, while the light MVNOs mainly focus on marketing operations, customer relations and optionally, billing systems and subscriber management. Lastly, the MVNEs provide core network, billing, and subscriber management systems in order to aggregate and facilitate light MVNOs with corresponding features. Even though the respective MVNO types have different capabilities and business focus, they share the issue of lacking a wireless network infrastructure.

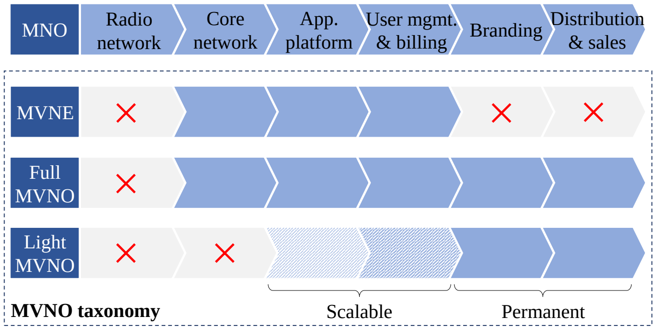

Fig. 1. MVNE, Full MVNO, and Light MVNO vs. MNO.

Fortunately, the rapid development and convergence of fifth-generation (5G) network softwarization technologies, including software defined networking (SDN), network function virtualization (NFV) and fog/cloud computing, present great opportunities for MVNOs. These technologies provide a harmonized and elastic infrastructure that is required for emerging applications and services such as social Internet of Things (SIoT), machine to machine (M2M) communications, over-the-top (OTT) services, and ubiquitous data mining [2], [3]. This fits perfectly into the strategy of next generation MVNOs, focusing on social services rather than traditional cost-oriented ones. As a result, global MVNO subscribers are expected to exceed 300 million by 2020, which represents a compound annual growth rate (CAGR) of 10.7% from 2014 to 2020 [4]. Unfortunately, the scarcity of technological and infrastructural knowledge, the dependency on the MNO infrastructure, and the associated contract constraints are issues that must be resolved in order to benefit from such opportunities. It is therefore necessary to find innovative ways that enable MVNOs to

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interact directly and control services on user equipment (UE) in order to successfully provide an increasing number of new services.

Most existing research aims primarily at exploiting cooperative solutions that share radio resources between MNOs and MVNOs. For instance, the MNO might lease out its free mobile channels to the MVNOs based on timing duration or specific services (e.g., voice and virtual private networking services). Such approaches are inspired by concepts from areas like game theory, cognitive wireless access methodology, and femtocell utilization [5], [6]. Although this provides the MVNO with some management and control of the access network infrastructure, in almost all cases, it also makes CAPEX and the network complexity increase proportionally. Moreover, there are no guarantees regarding business profits because the MVNO must balance the pros and cons of physical infrastructure investment.

In this article, we propose a feasible approach that provides alternative access methods for MVNOs. Based on 5G softwarization technologies, the proposed approach provides selective multipath device-to-infrastructure (D2I) connections between UEs and the network as well as service assortments. The selective multipath D2I connections flexibly choose appropriate communication resources for data delivery without a strict consideration of MVN's infrastructure restraints. The connections are configured following user networking policies supervised by SDN-based edge controllers. Provisioning data, which contains configurable policies and user information, is synchronized among devices owned by individual users. In addition, user services are classified with respect to predefined priorities before reaching the network. As a result, the MVNOs can minimize the dependency on the MNO's infrastructure within service management by cooperatively utilizing public infrastructures such as wireless Internet and device-to-device connections when applicable.

The main contributions of this article are as follows. First, potential opportunities and open challenges of MVNO development are investigated in the context of 5G softwarization. Second, we describe our proposed architecture, which utilizes 5G softwarization to provide virtual D2I connections in MVNOs. Third, pilot implementation is performed to verify the feasibility and enhanced services of our proposed architecture.

II. OPPORTUNITIES AND CHALLENGES

In this section, we highlight the opportunities brought about by the convergence of 5G softwarization technologies and the technical challenges that MVNOs currently face.

A. Opportunities

A key enabler of 5G network softwarization is cloudization. Cloudization comprises three technologies: NFV, SDN, and ubiquitous fog/cloud computing [7]. Ubiquitous fog/cloud computing is a distributed resource architecture that provides an infrastructure for big data mining from multiple applications in order to deliver actionable intelligence to users and businesses. SDN decouples control functions from network components, enabling the applications and network services to operate on top of a logical, programmable and centralized framework and underlying vendor agnostic hardware. In complement to SDN and fog/cloud computing, NFV transforms the network functions from dedicated, proprietary appliances into software platforms running on general purpose infrastructure to provide automated service delivery and orchestration [8]. Together, these three technologies provide a perfect environment for enabling a full MVNO deployment at a reasonable scale with acceptable costs.

In 5G communication networks, the access tier consists of heterogeneous technologies working together in a seamless and autonomous manner to provide a unified access network model, referred to as HetNet+ [8]. Hetnet+ consists of both wireless and wireline access technologies and operates in both licensed and unlicensed environments. Although the service quality provided by these technologies can differ, satisfactory service levels can be achieved by almost all technologies [9]. Therefore, this provides multiple access methods for user devices to MVNO networks, resulting in better service delivery.

Consequently, the pervasiveness of these technologies brings about new services, including social services such as SIoT, M2M, OTT, and ubiquitous data mining, as well as rich content services such as high resolution multimedia, real-time and virtual reality services. The trend towards social services may create opportunities for MVNOs to develop a variety of new customer segments. However, to realize these opportunities, MVNOs must address the accompanying challenges, described below.

B. Challenges

The fundamental problem faced by MVNOs is lack of a wireless access infrastructure because they do not possess any spectrum allocation [10], [11]. Additionally, since their focus is on niche market segments, it is pertinent to minimize investment in the network infrastructure and management in order to significantly reduce expenses and maximize returns. Therefore, to serve its customers, the MVNO must utilize an MNO's wireless infrastructure by leasing bundled access volumes of voice and data services. This dependency restrains the ability of the MVNO to develop new services and increases direct competition with MNOs in traditional market segments. Moreover, the dimension of MVNO networks is scaled to be very small in comparison to the MNO networks.

Furthermore, customer segmentation becomes even more difficult because of their rapidly changing requirements as well as the desire for multiple high-quality, feature-rich and low-cost services. For instance, retail customers interested in M2M services not only want a low price, but also require enhanced services like ubiquitous data mining and location tracking. In the discount segment, customers usually focus on data services, but may sometimes want high-quality voice and other real-time applications. If the user requirements are not satisfied, they are likely to move to other providers without concern for whether they are MVNOs or MNOs.

Although MVNOs are faced with increasingly complex requirements from customers, the MVNOs must consider the trade-off between minimizing the cost by reducing investment in network infrastructure and ensuring end-to-end quality of service. This creates a catch-22 situation because without full network management and control, quality of service is very hard to guarantee. Therefore, the survival of MVNOs requires a new approach and development of a dynamic network model.

III. System Architecture

In this section, we discuss how to utilize opportunities presented by 5G network softwarization technologies to address the challenges of the MVNO. We begin with a brief introduction of SDN technology and how it can help resolve such challenges. Furthermore, we propose a novel SDN-based approach for D2I management and service assortment and describe the detailed functions of the supplemented network components.

A. *Our Approach*

Most limitations of MVNOs arise from the lack of an end-to-end wireless network infrastructure due to cost and management constraints. Fortunately, these limitations can be addressed by developing a dynamic and flexible network model to support various new services through advanced 5G network softwarization technologies, especially SDN. SDN is a modern networking architecture that employs a standard based abstraction protocol (e.g., OpenFlow) between a centralized network controller and the underlying data-forwarding components (i.e., switches). This abstraction enables drastic improvements in network agility and management, and eliminates vendor dependency, which previously has not been possible. Importantly, the network controller facilitates customization of the network operations through a set of application programming interfaces (API). This facilitates the deployment of tailor-made applications that enable the execution of specific network functions. The network operation is controllable, programmable and automatic.

Therefore, by utilizing the advantages of SDN technology, we propose a novel solution that helps the MVNO network overcome the limitations of lacking access infrastructure. This solution supports flexible policies (through user service contracts) that reflect the custom service requirements of each user. Users design their own policies based on pre-specified service sets. On the user equipment side, an SDN-enabled switch component provides direct connections to the MVNO's infrastructure. Based on the selected policy, the user services can be prioritized and processed before leaving the device. If the user connects through an untrusted non-3GPP access network, then IPSec connections are used to secure the data and make them transparent during transfer across the access network. To increase flexibility, we suggest integrating a virtual subscriber identity module (VSIM) into the solution to make it possible to switch between MNOs to achieve the best performance.

B. *Proposed SDN-based Solution*

To provide a complete view of a state-of-the-art MVNO, we consider a full MVNO network model that has already been cloudized, as represented by the blue components in Fig. 2. Preferably, all typical network functions (e.g., home subscriber server, policy and charging rules functions) are maintained and virtualized using NFV technology [12]. The network operations, applications, and contents use cloud computing to improve performance and availability. The core and distribution network switches are controlled and managed by a routing controller (RC) entity using SDN technology. This architecture provides the MVNO with optimal performance at a reasonable cost [13], [14]. It is worth noting that these assumptions do not affect the proposed approach in terms of feasibility and operation.

The access network comes from other providers (e.g., other MNOs or Internet service providers) employing a variety of technologies, including wireless and wireline access methods, trusted and untrusted networks, and licensed and unlicensed mediums, as represented by the orange colored components in Fig. 2. The distinction among access types does not matter because the MVNO has no responsibility for physical access network management.

For these circumstances, we develop an SDN-based solution to provide a controllable D2I connection for the MVNO. The additional components are colored green in Fig. 2 and include the following. The SDN-enabled switch contains a user profile certification (UPC) and a service forwarding function (SFF) integrated into the user equipment, as well as an optional VSIM. In the distribution network, the aggregation points contain a user management and control (UMC) component (i.e., SDN controller) and aggregation routers (AR) (i.e., SDN switches). An SDN controller-based service management (SM) component is in the control plane of the core network, and a user profile data (UPD) component is added into the existing home subscriber server (HSS). The SDN-enabled switch establishes connections with the aggregation points as authorized by the SM. The connections and user services are controlled and managed by the UMCs using the user profile data provided by the UPD.

The light-weight SDN-enabled switch is integrated into the user device's mobile operating system. It allows the MVNO to process user data (i.e., prioritizing and routing) as soon as it leaves the applications. These functions are provided through the following modules:

- The UPC is responsible for mutual authentication between the user and the network. Each user has unique identity credentials. Note that this authentication process operates independently from the underlying access network. Moreover, when the VSIM is available, the UPC is responsible for negotiation with the network to deliver provisioning data to the VSIM, and then sends the selected service contract back to the network.
- The VSIM is optional in this solution. It provides the ability for the user to selectively enable provisioning data supporting one of the multiple MNOs stored in the VSIM's internal memory unit to conduct wireless communication [15]. Through the VSIM, the user has more choices regarding access to the network.
- The SFF is a lightweight SDN-enabled switch. The SFF receives flow entries and control messages from the UMC

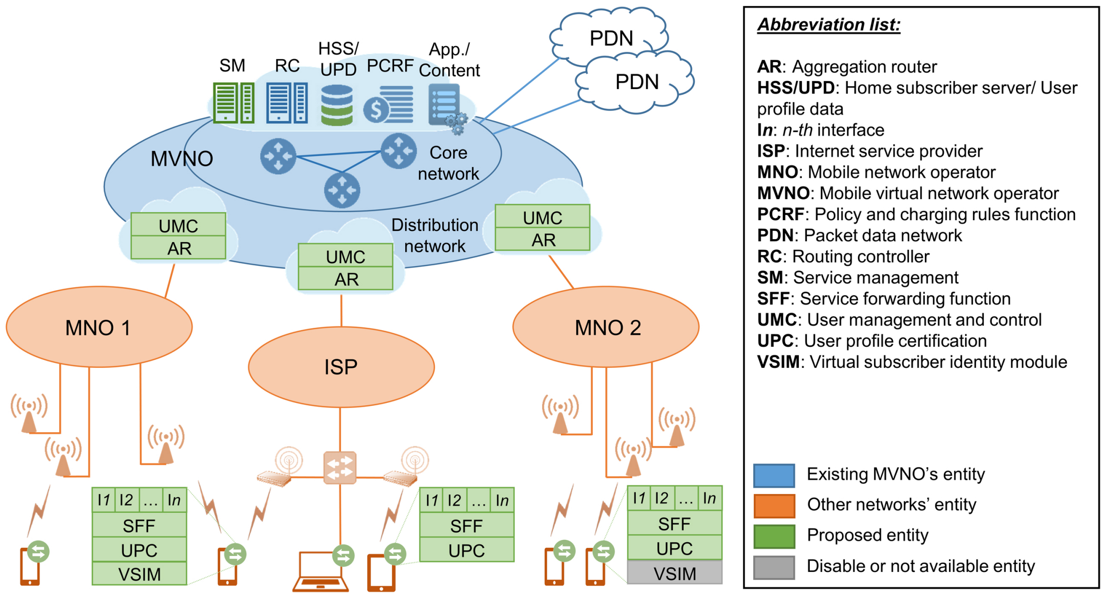

Fig. 2. SDN-based device-to-infrastructure approach for mobile virtual networks.

to prioritize and route different data packets out of the corresponding interfaces. The actions defined in the flow entries are based on the selected service contracts.

On the MVNO network side, the aggregation point consists of two components: UMC and AR. The detailed functions are as follows:

- The UMC operates in the control plane and has four main functions. First, the authentication process identifies the user upon initial participation in the network. Second, the UMC establishes and controls connections from multiple user devices to the AR. For each user device, the UMC assigns a separate set of flow entries corresponding to the selected service contract. If the user data has to be forwarded out of more than one interface due to the selected service contract (i.e., the user data arrive at different ARs), the UMC exchanges this information with the corresponding cooperating UMCs to route the user data correctly. Third, based on the report messages from the AR, the UMC extracts relevant data for billing. In the case of prepaid services, a special flow entry is dispatched to the user device to define a barrier against the user data. Fourth, a lawful interception will be provided upon request from government authorities by issuing the corresponding flow entry into the AR.
- The AR operates in the data plane. Its responsibility is to gather connections from user devices and process user data based on flow entries defined by the UMC. Moreover, the service slicing technique [16] can be utilized to classify data traffic and forward it to the core network.

In the core network, the SM server responds to authentication requests from users and manages user service contracts (i.e., issuing, modifying, and deleting service contracts) during the negotiation process. The user profile data and service contracts are stored in the UPD database in the HSS server.

IV. SDN-BASED D2I CONNECTION AND SERVICE ASSORTMENT

This section presents the D2I establishment procedures and service assortment in detail. In order to address security concerns, we propose D2I establishment procedures in two typical scenarios.

A. D2I Connection

Fig. 3 shows the D2I establishment procedure in two typical cases: a) The VSIM is enabled (i.e., the user device is able to access contracted MNO networks); and b) The VSIM is disabled (i.e., there are no contracted MNO networks available in this area) or not available (i.e., the user device does not support the VSIM module).

As shown in Fig. 3(a) – when VSIM is enabled, the D2I connection is established through three steps:

- *Step 1:* The UPC and UMC initiate a mutual authentication process. Because the VSIM is enabled and the user device is connected to a contracted MNO, the EPS-AKA[1] protocol is used. However, if the underlying access network is untrusted such as Internet service provider (ISP), the EAP-AKA within the IKEv2[2] protocol is used. The authentication vectors stored in the HSS server are forwarded from the SM to the UMC.
- *Step 2:* After successful authentication, the service contracts are provided to the UPC. According to their particular requirements, the user selects the preferred one and sends it back to the UMC. Simultaneously, the UPC forwards the provisioning data to the VSIM to store for the purpose of switching the contracted MNO.

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[1] EPS-AKA stands for Evolved Packet System Authentication and Key Agreement.

[2] EAP-AKA over IKEv2 stands for Extensible Authentication Protocol for Authentication and Key Agreement within Internet Key Exchange version 2.

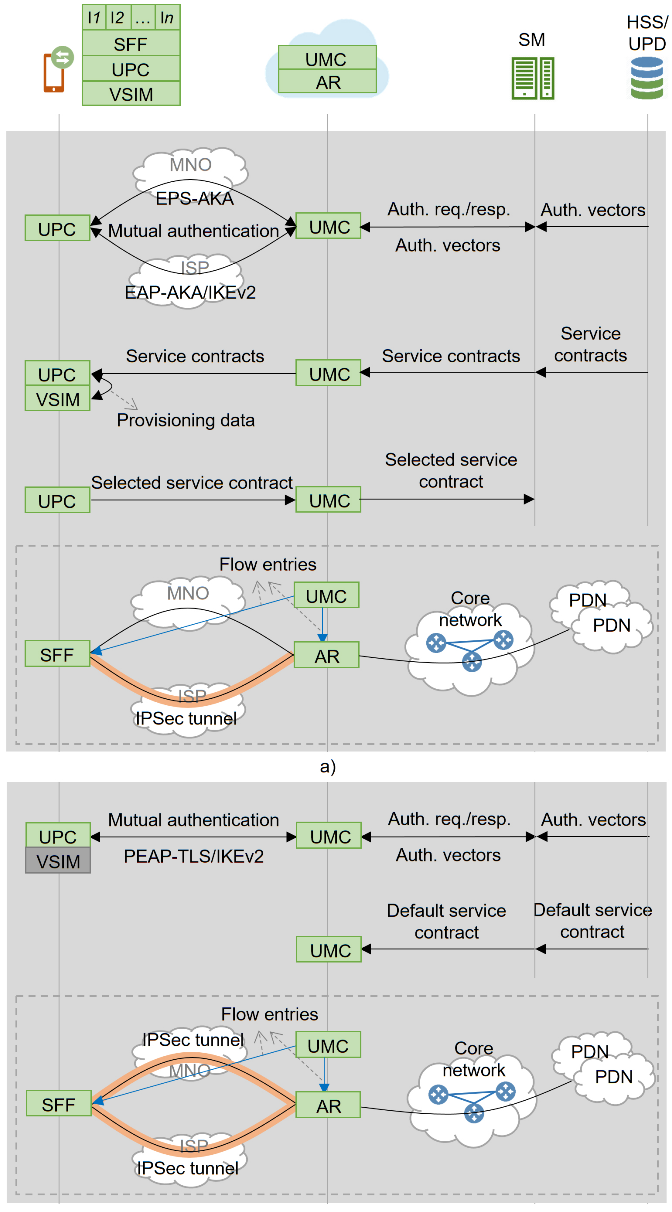

Fig. 3. D2I establishment procedure: a) VSIM is enabled; b) VSIM is disabled or not available.

- *Step 3:* Based on the selected service contract, the UMC issues the corresponding flow entries into the SFF and the AR, and establishes data connections between them. If the data connection is over the ISP network, an IPSec tunnel is used to secure the user data.

Alternately, Fig. 3(b) shows the case in which the VSIM is disabled or not available. The D2I connection is established through the three steps below:

- *Step 1:* The UPC and UMC initiate mutual authentication using PEAP-TLS[3] within the IKEv2 protocol, regardless of the kind of underlying access network.

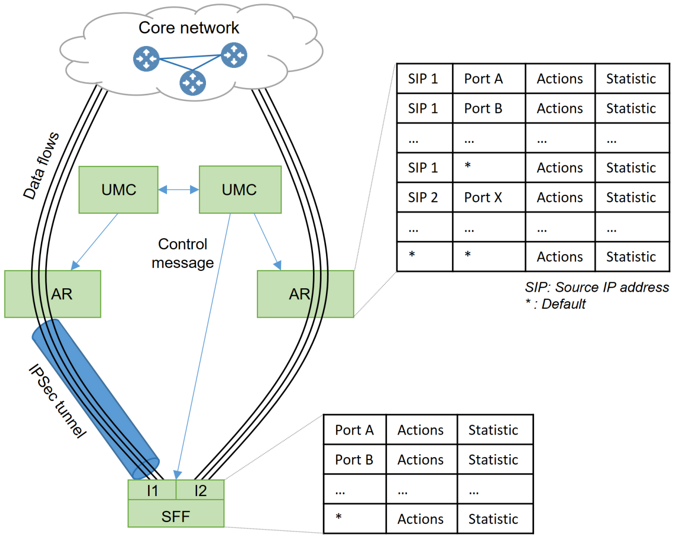

Fig. 4. An example of the service assortment in a D2I connection.

- *Step 2:* The UMC is provided with the default service contract from the SM. Due to the lack of user identity from the VSIM, the user device is restricted to a negotiation process.
- *Step 3:* Based on the default service contract, the UMC issues the corresponding flow entries into the SFF and the AR. Regardless of the kind of underlying access network, IPSec tunnels are used to secure the user data.

B. Service Assortment

Fig. 4 shows an example of the service assortment in SDN-based D2I connections. The user device has two mediums by which to connect to the network: through the contracted MNO infrastructure and the wireless ISP network. Depending on the pros and cons of each connection, the UMC generates the corresponding flow entries to prioritize and process data packets arriving at the SFF as soon as they leave the applications based on the policy defined in the selected service contract. The service assortment uses the output interfaces and service ports to classify the user data. For example, the voice service requires low throughput but short delay, therefore, it is routed through a cellular interface and assigned a specific service port number for further processing in the AR. For a file transfer, the data is forwarded to the WiFi interface to obtain a high data rate without direct cost since the most important requirement is high throughput.

On the AR side, source IP addresses are used to further classify user data according to service contracts. All policies may be updated through modified flow entries that are managed by the UMC.

V. FEASIBILITY VALIDATION AND BENEFIT

To validate the feasibility of the proposed SDN-based D2I connection and its operations in different scenarios, we develop a pilot network model that consists of both LTE and WiFi access networks (see Fig. 5). The network model is deployed in two consumer off-the-shelf (COTS) x86-based

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[3] PEAP-TLS stands for Protected Extensible Authentication Protocol within the Transport Layer Security tunnel.

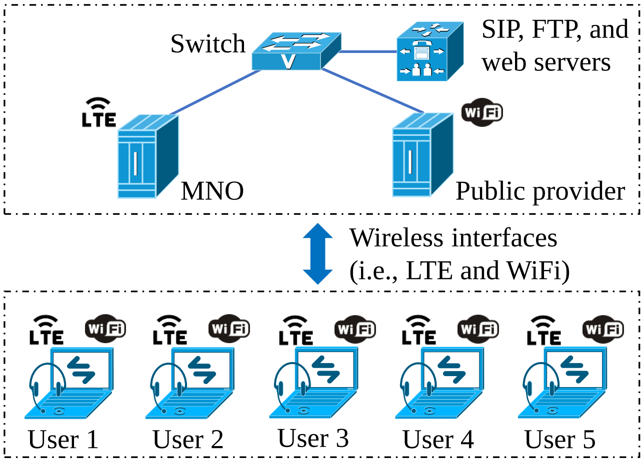

Fig. 5. Pilot network model.

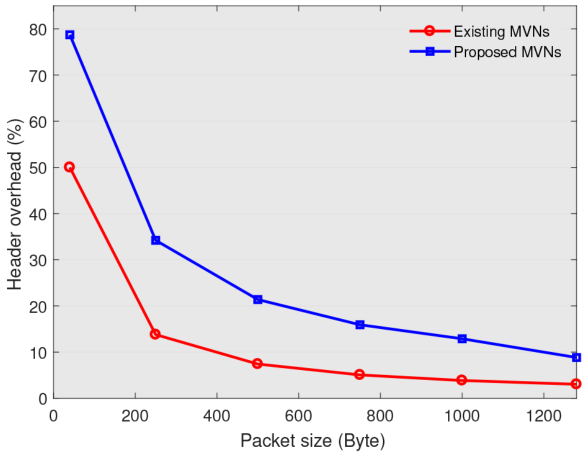

Fig. 6. Header overhead comparison between the existing MVNs and the proposed MVNs.

TABLE I
SYSTEM PARAMETERS.

Parameters	**Value**
Bandwidth	10 MHz
Frequency	2.4 GHz
Transmit power	15 dBm
Receiver sensitivity	-100 dBm
Service cost	3 unit/MB (LTE) 1 unit/MB (WiFi)

servers with an OpenFlow protocol to represent an MNO (LTE connection) and an ISP (WiFi connection). The SFF and AR are based on Open vSwitch. The secure connection between the SFF and the AR is provided by an additional module. Five Raspberry Pi 2 model B machines are implemented as the user devices. In addition, one server is installed to provide voice and data services. The voice data is generated based on session initiation protocol (SIP) transmissions supported by the 3CX SIP software. Meanwhile, data is also generated by FTP and HTTP protocols transmissions via FTP and web servers as well. Additional system parameters are provided in Table I.

The experimental scenarios are built based on different user service contracts. For simplicity, we divide the user data into two categories: voice and data. The user chooses either `quality` or `cost` as the priority for voice and data service contracts as follows:

- *Contr. #1:* `voice -> quality; data -> quality.`
- *Contr. #2:* `voice -> cost; data -> cost.`
- *Contr. #3:* `voice -> quality; data -> cost.`

To ensure fairness in the performance comparison, we only consider value-added services (i.e., SIP calls, FTP transfers, and website accesses) provided by the MVNO since data services might be transferred to public WiFi connections beyond the MVNO's control or management whenever it is available. For performance evaluation, 500 sessions of Monte Carlo voice and file transfer experiments are performed for each service contract in five user devices.

Fig. 6 shows the overhead increase due to IPSec encapsulation in the proposed solution compared to existing MVNs [16], which provides a slicing technique to prioritize different applications at the access network. It is worth noting that both evaluated MVNs share the same architecture elements in the access and core networks, but with distinguished logical functions depending on their own schemes. The proposed MVNs introduce two new elements (i.e., the SFF and UPC) in user devices compared to the existing MVNs. The results show that the difference in overhead decreases from 28.72% to 6.80% when the packet size increases from 40 Bytes (e.g., voice packet) to 1280 Bytes (e.g., data packet). This means that the effect of the extra overhead becomes insignificant as the packet size grows. In other words, almost all data services can be acceptable. Meanwhile, although small communications might suffer from encapsulation overheads, the light traffic volume results in insignificant overhead compared to the data services.

In Fig. 7, the box-plot representation illustrates the communication latency depending on service contracts in two stages: the initial stage and the session connection stage. The statistical results reveal that the average communication latencies of (*initial stage, connection stage*) when using service contracts #1, #2, and #3 are (8.55, 1.71), (15.13, 3.08), and (12.58, 2.45) ms, respectively. The diversity of communication latency is close between service contract #2 and service contract #3 since service contract #3 flexibly manages data services within WiFi connection instead of the LTE interface. Meanwhile, service contract #1 truly provides the lowest average latency due to its LTE usage. In spite of the existing difference, the communication latency results of the three experimental service contracts are within acceptable limits of 5G services [17].

Table II shows a performance comparison between the proposed MVNs (via three contracts) and the existing MVNs (via LTE or WiFi connections). The proposed MVNs demonstrate an impressive performance of service prioritization in terms of latency. Because the proposed MVNs support service assortment from the user device as well as at the AR, voice service is processed with a higher priority. The average voice latency in contracts #1 and #3 is lower than that of the existing LTE-based MVN by approximately 0.65 ms, while

TABLE II
PERFORMANCE COMPARISONS.

Parameters	**Existing MVNs**		**Proposed MVNs**		
	LTE	**WiFi**	**Contract #1**	**Contract #2**	**Contract #3**
Average voice latency (ms)	1.508	2.677	0.852	1.747	0.858
Average data latency (ms)	1.692	2.911	1.904	3.338	2.915
Average latency differential (ms)	0.184	0.234	1.052	1.591	2.057
Additional cost with fixed-rate WiFi pricing (unit/s)	+165.194	0	+170.884	0	+17.833
Average cost with volume-based WiFi pricing (unit/s)	165.194	61.780	170.884	65.618	83.451
Average goodput (bps)	49,257,236	43,903,188	47,616,970	41,334,852	43,335,937
Energy consumption (J/s)	3.442	3.861	3.560	4.101	3.912

TABLE III
NEW FEATURES AND BENEFITS FOR THE MVNO AND CUSTOMERS.

New features	**Existing MVNs**	**Proposed MVNs**	**Benefits**	
			MVNO	**Customer**
Multi-user profiles	No	Yes	Extend the logical coverage area	Have more choices to access the network
Controllable D2I connection	No	Yes	Reduce the dependency on MNO access infrastructure	Improve security for user connections
Service assortment	Limited (in core network [16])	Enhanced (from the user devices)	Sort outgoing data regarding service priorities	Satisfy different service requirements
Value-added and OTT services' support	Limited	Enhanced	Exploit more new customer segments	Reduce the communication service expense and have more available services

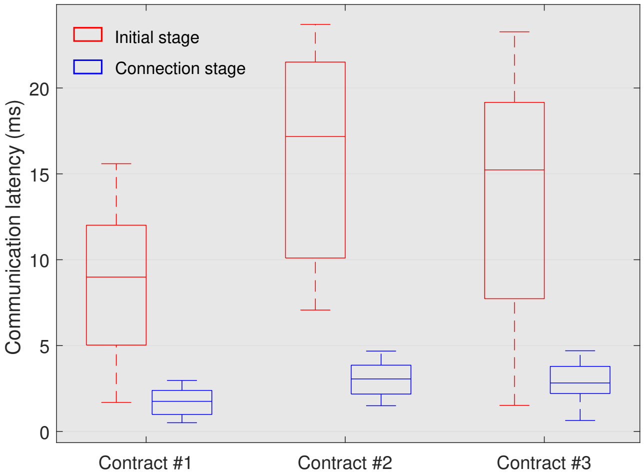

Fig. 7. Communication latency depending on service contracts.

the difference between contract #2 and the existing WiFi-based MVN is approximately 0.93 ms. Since the data services are considered to be latency-tolerant, they are assigned lower priority than the voice services'. The average latency differential between voice and data services shows that contract #3 provides the best performance in prioritizing user services (a higher differential is better). In other words, multiple time-sensitive IoT applications in the 5G era can be effectively served by the proposed MVNs along with traditional data applications.

For service cost comparison, we considered two pricing policies: (i) a volume-based policy for both LTE/WiFi connections and (ii) a volume-based LTE pricing and fixed-rate WiFi pricing policy. The volume-based pricing policy is adopted by operators for service delivery to the users, e.g., 3 unit/MB for the LTE connection and 1 unit/MB for the WiFi connection [5]. Within the assumption of fixed-rate WiFi pricing, contract #1 pays a 3.44% cost increase for data encapsulation and control overheads to obtain a good latency differential compared to the existing LTE-based MVN. On the other hand, contract #3 is reduced to a 89.56% cost by using a WiFi connection; however, it still achieves approximately the best latency performance as is obtained by contract #1. In case the volume-based policy is applied for both LTE and WiFi connections, contracts #2 and #3 have a lower cost than the existing LTE-based MVNs by 60.28% and 49.48%, respectively, due to their WiFi utilization. Contract #1 is the most expensive in terms of service cost while the existing WiFi-based MVN is the cheapest.

Despite introducing great performances in terms of service prioritization and QoS-cost balance, the proposed MVNs have IPSec encapsulation and control overheads on the D2I connections from the UMCs and ARs to the SFFs. These overheads lead to an average goodput decrease and an average energy consumption increase, both by approximately 6%. Note that the goodput has been monitored in time-varying wireless channel conditions due to environmental factors and user mobility.

In summary, the proposed SDN-based D2I connection solution introduces some new features and capabilities, including multiple access methods via multiple user profiles, controllable D2I connections and user service assortments based on SDN-supported protocols, value-added and OTT services support, etc. As a result, the MVNO is able to overcome the limitations of lacking a physical wireless access infrastructure to provide diverse services to its customers. Furthermore, the customer requirements with respect to quality and cost are satisfied better due to the D2I management capability of the MVNO. The detailed benefits for the MVNO and the customers are presented in Table III.

VI. CONCLUSION

One of the biggest factors that negatively impacts the development of MVNOs is the lack of access infrastructure. In this article, exploiting the supportive 5G network softwarization, we proposed a novel SDN-based D2I connection to overcome this limitation. This approach provides selective multipath D2I connections and service assortment for the users. The user services are classified with respect to their priorities before reaching the networking infrastructure. The feasibility and performance of the proposed approach have been validated through three typical experimental scenarios. The results show that the proposed approach provides new features in the network as well as additional benefits to both MVNOs and their customers. Particularly, the service assortment prioritizes user services throughout the D2I connection. Therefore, it promotes time-sensitive 5G applications to be served by the MVNOs. Although the proposed approach provides significant advantages, it also has some limitations. In most cases, the D2I connection utilizes an IPSec tunnel for data transfer between user devices and the network. This usually requires users to install a new application on their devices, which may be impossible for certain low-end devices. These limitations may be the focus of future research.

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