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Mobile Virtual Network Operators
A Software Defined Mobile Network Perspective

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16.1 Introduction

Wireless networks demand dynamic, innovative, and user-centric business models for emerging markets of mobile and wireless communication system. Current trends demand flexible and wide range of services for mobile end users. Mobile network operators (MNOs) with licensed and unlicensed spectrum function as the potential stakeholders in wholesale and retail business markets for mobile networking and communication services. MNOs are the primary licensed vendors and depend on virtual network operators (VNOs) to meet the demands of end users. Mobile virtual network operators (MVNOs) [1] lease the radio spectrum from MNOs and extend the infrastructure from MNOs and third-party service providers to potential mobile end user nodes (MEUNs). MVNOs are not assigned the licensed spectrum by regulating bodies and hence operate using the unlicensed radio spectrum for short-distance communication. MVNO's leased radio spectrum is based on service agreements (wholesale and retail) with MNOs and the density of MEUNs. MVNOs support value-added services like high-speed data, multimedia streaming, video conference, E-commerce, M-commerce, etc. Virtual private network systems (VPNS) enable the MEUNs to install and utilize the user services within the private domain by working in collaboration with third-party network operators [2].

MVNOs create a virtual interface framework to manage and monitor the services and requests from subscribed MEUNs, MNOs, and access points. MVNOs like active network operators use packet processing, filtering, and forwarding mechanism in the network. Virtual interfaces do not define the service packages, but maintain the complete business details of service providers and function as access point black box in the mobile network. Virtual interfaces address resource partitioning, multiplexing, and demultiplexing in the network. The

Software Defined Mobile Networks (SDMN): Beyond LTE Network Architecture, First Edition.
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number of MEUNs subscribed to MVNO depends on the existing business model such as one to one and one to many. The interaction between MNO and MVNO is based on Business Service Subsystem (BBS), Network Service Subsystem (NSS), Application Service Subsystem (ASS), and User-Supportive Subsystems (USS) and configured through the attributes of software defined network (SDN). Figure 16.1 illustrates various types of services between MNO and MVNO controller by SDN. SDN controller configures and maps the services between MNO and MVNO as per the service requirements of MEUNs. Table 16.1 highlights the SDN configuration metrics and their respective attributes used in MNO and MVNO business model.

The salient features of each subsystem as illustrated in Figure 16.1 are elucidated as follows:

BSS: This subsystem defines the business framework for existing market demands, license agreements with MNOs, types of services, and pricing tariffs to MEUNs. BSS includes spectral sharing factor and quality of bandwidth during peak traffic periods. MVNOs define several branded services with respect to multiple MNOs.

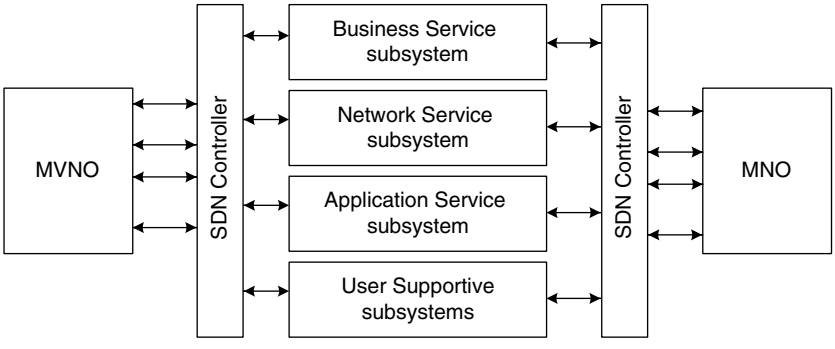

Figure 16.1 Services between MNO and MVNO controllers by software defined network.

Table 16.1 SDN Configuration Metrics and Attributes used in MNO-MVNO Business Model

Configuration Metrics	Attributes
Configure Control Plane	• Set logical paths • Set alternate paths • Set fault tolerant paths
Configure Data Plane	• Flow of voice and data packets (size, path, etc.) • Prioritize data packets
Load Balancing	Balance the load across MNOs and MVNOs
Spectrum Allocation Schemes • Cooperative • Non-Cooperative	• MNO regulates the allocated spectrum range with respect to the number of MVNOs • Resource allocation is prioritized for commercial and value added MEUNs
Spectrum Access Technique • Overlay • Underlay	• Wholesale and retail pricing schemes are based on dynamic spectrum allocation methods • Efficient switching methods for guaranteed MVNO-MNO networks
Security	Firewalls, VPN, etc.
Application Service	Value added services, Voice mail, etc.

NSS: This subsystem defines the networking model of MVNO with mobile bearer services such as PSTN, GPRS, GSM, UMTS, LTE, and LTE-A. The channel specifications (such as bit transfer rate, SNR, transmitting power, receiving power, multiplexing, multiple accessing techniques, etc.) and user-specific parameters (such as bandwidth, time delays, packet transfer rate, power specifications, etc.) are the primary attributes of this subsystem.

ASS: This subsystem defines the service specifications for MEUNs with pricing and tariff schemes. MVNO physical location is estimated as per the business strategy and density of MEUNs. MVNO offers the application services such as voice, high-speed data, video, SMS, multimedia, Internet applications, etc. to MEUNs. The business and networking specifications with QoS parameters are manifested in this subsystem. The services offered in this subsystem are classified as follows:

Class I Excel: Applications that demand high-speed and efficient services with maximum bandwidth (longer or shorter duration) are used in this class. Such premium services are used in commercial applications for multination organizations, financial and banking sector, weather forecast, etc.

Class II On Demand: Applications that require consistent services during catastrophic events such as fire accidents, earthquake, tsunami, etc. are used in this class. These applications demand maximum bandwidth for shorter duration with high-speed SMS and data transfer rates.

Class III Economical: Applications with high-speed data services and adaptive bandwidth allocation used in this class. Such flexible services are used in medium-scale organizations such industries, hospitals, corporate offices, etc.

Class IV Regular: Application service requirements of MEUNs based on PSTN, IPTV, Access Point services, etc. are used in this class.

USS: This subsystem addresses the potential demands of MEUNs and facilitates additional services and packages offered by the neighboring MNOs. Retail tariff and pricing schemes are defined in this subsystem.

16.1.1 Features of MVNO

MVNOs are a collection of distinct unlicensed operators that outsource their radio operations to reliable networks and support value-added services to MEUNs. Unique identity is assigned to the MVNO subscriber such as the subscriber identity module (SIM). The MVNO transactional cost is reduced by subdividing the task and distributing it to neighboring MVNOs. Time-frame negotiations limit the potential hazards in transaction and support the ACID features [1]. Software defined network (SDN) [3] adds the reconfigurable mobile network parameters to the existing MVNO and enhance the services to MEUN. Reconfigurable parameters used by SDN are given as follows:

- Network capacity specifications defined by traffic controller and maximum transmission unit (MTU)
- Cognitive and dynamic switching techniques for UMTS, GPRS, and TCP/UDP-based services

- Gateway connectivity and route discovery protocols
- Update of MEUN database and lookup tables
- Update of MEUNs mobility management services
- Secure key management for encrypted data packets.

Software defined mobile network (SDMN) [4] architecture for future carrier networks decouples the data and control planes in mobile network. SDMN supports VNO interface and application program interfaces (API) to enhance the services of carrier network, network coverage, and proxy gateway nodes.

16.1.2 Functional Aspects of MVNO

The functional aspects of MVNOs are elucidated as follows:

- **Bearer Services and Gateway Interfaces**: Earlier business models of MVNO were designed for UMTS [5] that support medium-scale data services. The service aspect of MVNOs is a function of bearer services and gateway interfaces.
- **Centralized and Distributed MVNOs**: The services of centralized and distributed MVNOs are based on the density of MEUNs, the number of active MNOs, and the interface coordination units in the network. Various functions of MVNO servers are given as follows:

  (i) MVNO server maintains the user profile and service set.
  (ii) MNO server maintains the specifications of service set controlled by the network.
  (iii) Network server manages and controls the tasks of MNO and gateway nodes internetworking protocols.
  (iv) Proxy server addresses the license agreements and connectivity between heterogeneous API and network service providers.

16.1.2.1 Software Defined Network Perspective

The functional aspects of MVNO based on SDN perspective are illustrated in Figure 16.2. The functionality of each component is explained as follows:

- **Scalable and Secured Interfaces**: MVNOs define scalable network interface for virtual schemes [6] in varying traffic conditions. MNOs maintain the list of local and global operators to facilitate connectivity in wide coverage area and high-speed data access. For fair negotiations between MVNO and MEUNs, the parameters such as trust, privacy, compatibility, and sustainability are defined in the service set. Negotiation-based schemes [7] effectively satisfy machine-to-machine requirements, trust, and cooperation with existing VNOs.
- **Customer-Driven Server**: MVNOs operate based on customer-driven services (such as buy service, share service, value-added service, Internet-enabled service, etc.) that are flexible and adaptable in competitive business market. MVNO's user-centric approach [8] concentrates on the economic relations between MEUNs and MNOs. Horizontal marketing schemes by MNO (wireless access networks, WLAN, WWANs, etc.) use a different set of license agreements and offer their services to MVNO.

- **Regulation and Management Schemes**: Regulation schemes define access rights, QoS parameters, extended service sets, policy issues, and price tariffs for the interconnection network. Regulation schemes [9] in mobile communication market are a function of time–size–growth of business and variations in market strategy. Management schemes control the number of potential VNOs and compatibility with existing business models based on technologies like 3G, 4G, WiMAX, LTE-A, etc.
- **Spectral Utilization Services**: Efficiency in bandwidth utilization is implemented [10] by identifying the unused spectrum regions and allocating this region to VNOs with shared services.
- **Emergency-Supportive Services**: MVNO supports emergency services such as disaster management, natural calamities, etc. by establishing a flash network of cooperative MVNOs. Network operators at affected areas and critical service points are prioritized to access the MVNOs and base station (BS).
- **Extending Services of Virtual Enablers:** MVNOs support virtual enablers to provide the access rights for mobile virtual network enabler (MVNE) subscribers in the network.

16.1.3 Challenges of MVNO

MVNO comprises of infrastructureless network and integrated services of network service providers that support advanced mobile technologies such as LTE-A, 4G, etc. Various challenges of MVNO are given as follows:

Flexible Services—MVNOs offer flexible services to MEUNs and support scalable services for multidimensional MVNOs and MNOs in a distributed environment.

Ceaseless Connectivity and Mobility Support—With homogeneous and heterogeneous MNOs, MVNOs support seamless connectivity for internetwork and intranetwork systems. MVNOs support mobility across the various VNOs in the network.

Cost Effectiveness—MVNO business model specifies the service set parameters for MNOs, uses the unlicensed spectrum, and minimizes the operational cost of MEUNs. This potentially increases the marketing scope of VNOs.

Service Agreement—Sequence of MVNO service agreement plan is as follows: (i) sign the business agreement with MNOs, (ii) establish a business relationship with neighboring MVNOs, and (iii) support the MEUNs across various countries.

Security—Customer profile and service specifications are kept confidential in the virtual network. Based on MVNE requirements, MVNO configures the secure VPN to establish a secure communication channel.

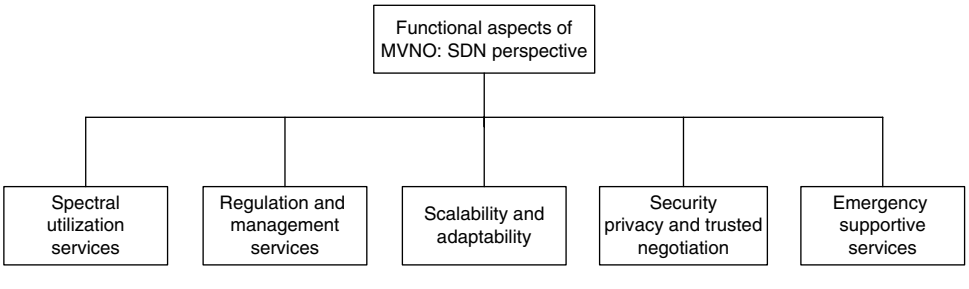

Figure 16.2 Functional aspects of MVNO.

16.2 Architecture of MVNO: An SDMN Perspective

SDMN comprises of SDN controller, SDN configuration interface, access points, HLR–VLR updates, mobile switching center, gateway servers, and BS. Figure 16.3 illustrates the architecture of SDMN-based MVNO that comprises of a set of MEUNs, access points, SDN interface, SDN controller, HLR–VLR components, MNO service point, gateway servers, and MVNO servers. User-defined unit comprising of authentic MEUNs and access points is connected to SDN configuration unit. SDN controller unit comprises of subcontroller units that configure the SDN parameters such as radio spectrum range, bandwidth, data rate, resource allocated, and service set. MEUN profiles are maintained in the subcontroller units that control and coordinate the services (Class I Excel, Class II On Demand, Class III Economical, and Class IV Regular) offered by MNO. MVNOs are connected to MNO service point and interact with MVNO server units through the gateway network.

16.2.1 Types of MVNOs

Various types of MVNOs [11] and their respective operations are highlighted as follows:

Full MVNO—Full MVNOs established by governing regulatory bodies and telecom operators are equipped with core network, access network infrastructure, and functional aspects such as routing, interconnection, and executable service list. The business model of full MVNO comprises of customer care service, billing, handset management, marketing and sales, etc.

Intermediate MVNO—Intermediate MVNOs access the radio spectrum and services of MNO. The business model of intermediate MVNO comprises of application services, customer care, billing, handset management, marketing and sales, etc.

Thin MVNO—Thin MVNOs support enhanced application services and increase the level of adaptability for MEUNs. Thin MVNOs support the services of MNO. The business model offers the best services for potential MEUNs.

Special Purpose MVNO—Special purpose MVNOs use specific MNOs with partial infrastructure for private and confidential applications. Special purpose MVNOs are used in corporate offices, business establishments, medium-scale industries, etc.

16.2.2 Hierarchical MVNOs

Hierarchical MVNOs [12] are based on network design, functional services, and business strategy used by VNOs. Various types of hierarchical MVNOs are explained as follows:

Single MVNO—Single MVNO comprises of adaptive business strategies for MEUNs, high-speed network, and efficient interface systems to interact with MEUNs. Single MVNO provides best possible services and package tariffs as compared to multiple MVNOs.

Multiple MVNO—Multiple MVNOs define the business strategies for MEUNs without the intervention of external agent or aggregate VNOs and establish the network with shared resources.

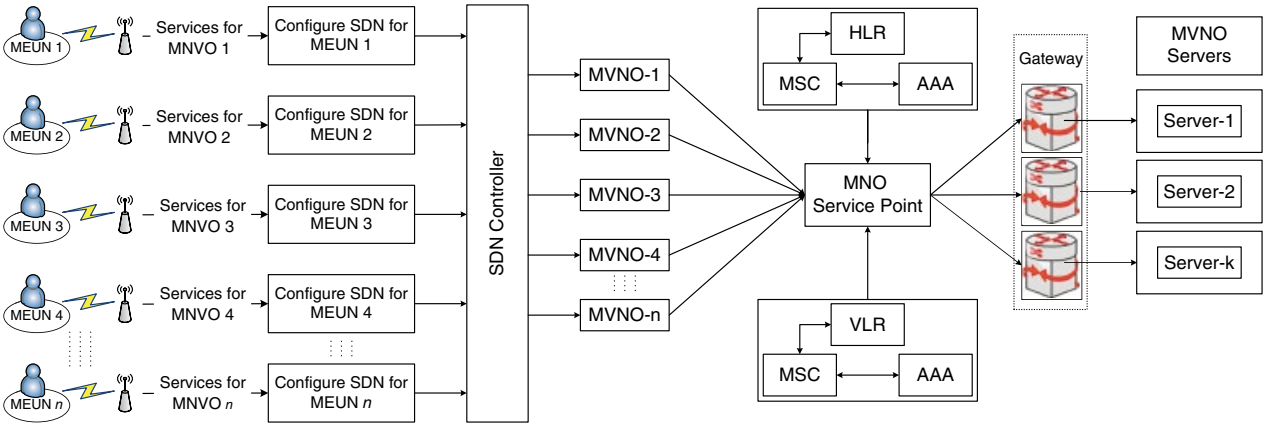

Figure 16.3 Architecture of SDMN-based MVNO.

Aggregator MVNO—To facilitate collective requests between MVNOs, aggregator MVNO acts like a bridge between the MNOs and MEUNs. MVNO aggregator comprises of distributed MVNO components, sophisticated interfaces, and MEUN's service request set. Mobile virtual network aggregator (MVNA) negotiates the license agreement, network capacity, and services with MNO, aggregates the services of different host MNOs, and specifies the price tariffs to hosting MVNOs.

16.3 MNO, MVNE, and MVNA Interactions with MVNO

MNOs and MVNOs sign the business contract and offer reliable services to retain their respective brand names in the open market. Regulating government organizations assign the licensed radio spectrum to potential network operators, and the business establishments are carried out at (i) network operator level and (ii) service point level. MNOs share the radio spectrum, control the network capacity, and work in coordination with MVNOs, MVNE, and MVNA.

Cognitive and SDN strategies enhance the performance of MVNO, MVNE, and MVNA by reducing the signal-to-noise ratio and packet loss. SDMN configures the radio and service parameters of MVNO, MVNE, and MVNA at distinguishing levels (level 1, level 2, and level 3) as illustrated in Figure 16.4. This scheme enables the network components to select the best available MNO based on (i) the available radio spectrum, (ii) connectivity with distinct MVNOs, and (iii) application services. This approach competes with existing service providers [10] in business market. Virtual resources at MVNO, MVNE, and MVNAs use "allocate-on-demand" approach and reduce the ambiguity in connecting with high-speed MEUNs. Cognitive access points (CAP) connected with multiple network operators extend their services in the coverage area by forming a grid. CAPs are context aware and define distinctive business services between MNOs and virtual operators such as MVNO, MVNE, and MVNA. MNO business strategy [13] is a function of VNO, authentic MEUNs, and value-added services of the network operator. Network operators are classified as (i) primary operator (PO), MNO, and (ii) secondary operator (SO), MVNO, MVNE, and MVNA. The price tariffs for MEUN SO are categorized as high-price (U_{hp}), medium-price (U_{mp}), and low-price (U_{lp}) services. Consider a network with an N number of active MEUNs distributed over an R number of MNO regions. With MVNO as the potential operator per region, SDN parameters are defined as follows:

Regional-Level Spectral Efficiency ($RL_{\text{se-MVNO}}$): $RL_{\text{se-MVNO}}$ is defined as the sum of products of transactional power and the number of potential licensed users for each service provided by MNO. Regional-level spectral efficiency is given as follows:

$$RL_{\text{se-MVNO}} = \sum (P_{\text{T-hp}} \times U_{\text{hp}} + P_{\text{T-mp}} \times U_{\text{mp}} + P_{\text{T-lp}} \times U_{\text{lp}}) \tag{16.1}$$

U_{hp}, U_{mp}, and U_{lp} are the number of high-, medium-, and low-level services offered to MEUNs.

Average Business Tariff per Service ($BTariff_{\text{Avg, Service}}$): The business tariffs for each service vary with MNO configurations. $BTariff_{\text{Avg, Service}}$ is defined as the ratio of product of power

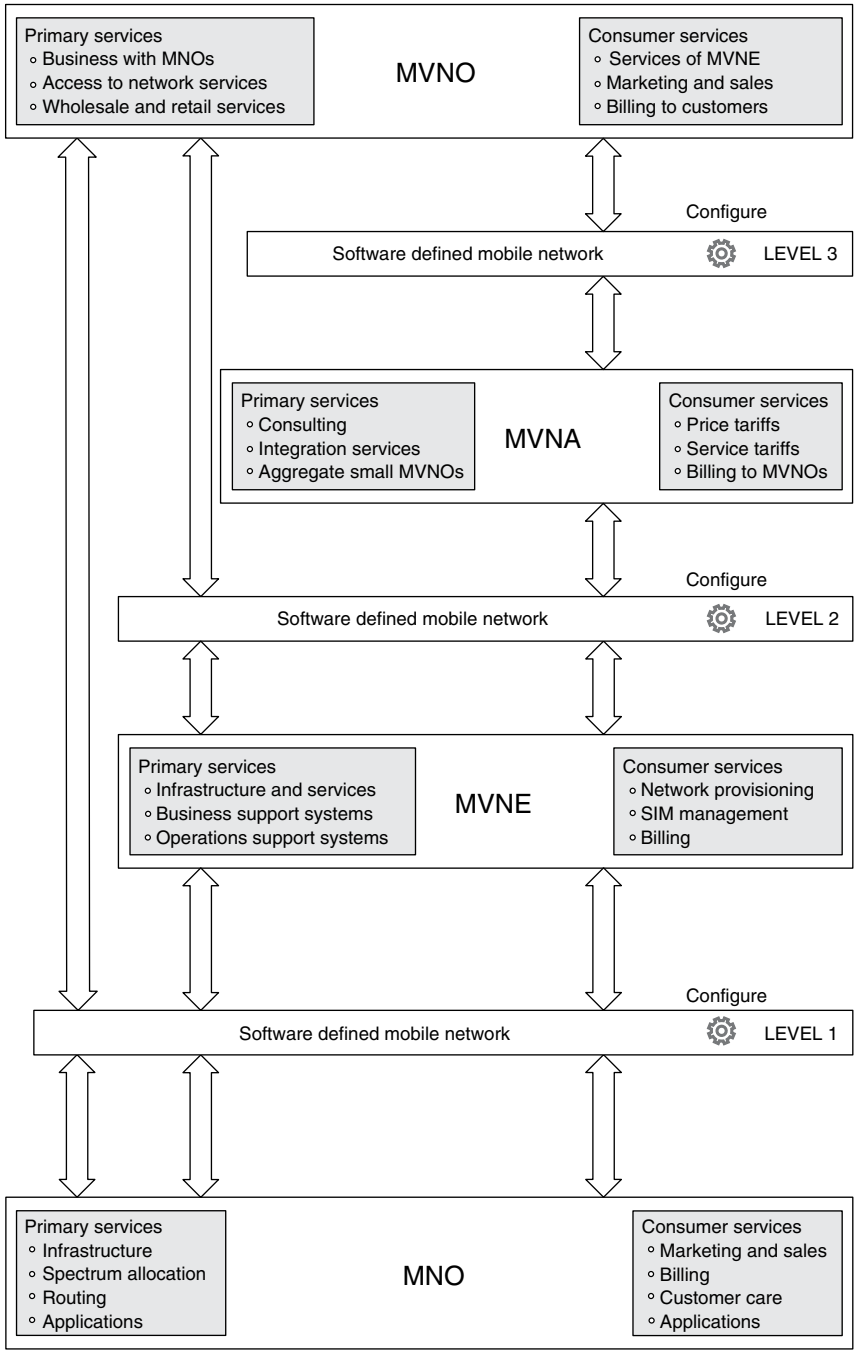

Figure 16.4 MNO, MVNE, and MVNA interactions with SDMN-based MVNO [11, 12].

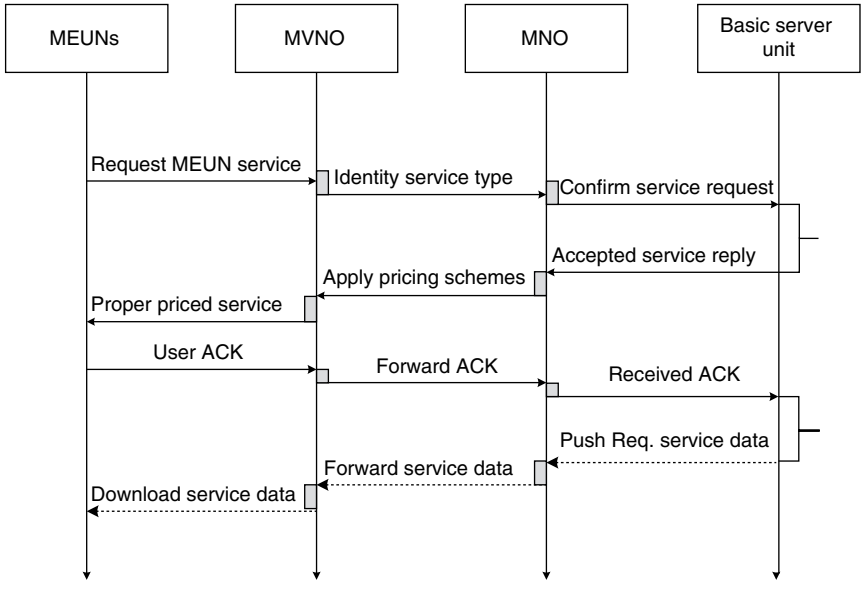

Figure 16.5 Sequence flow between MEUNs to basic server unit in home network domain.

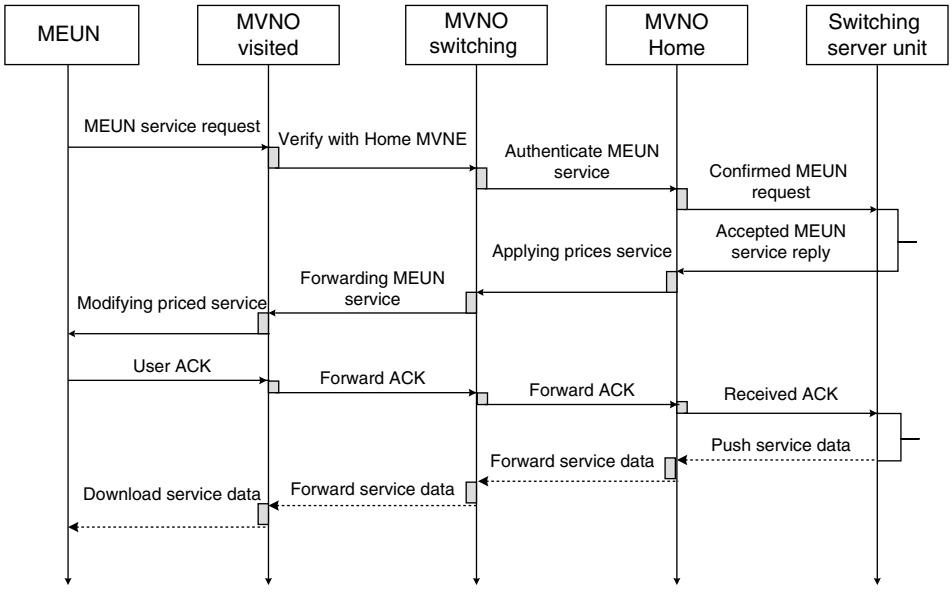

Figure 16.6 Sequence flow between MEUNs to switching server unit in foreign network domain.

required by each service ($P_{\text{T–service}}$) and total cost of service ($\text{cost}_{\text{service}}$) to the subscribed MEUN services (U_{service}). The average business tariff is given as follows:

$$BTariff_{\text{Avg, Service}} = \frac{P_{\text{T–service}} \times \text{cost}_{\text{service}}}{U_{\text{service}}} \tag{16.2}$$

The sequence of events in home network domain from MEUNs to MVNO, MNO, and basic server unit is illustrated in Figure 16.5. In the foreign network domain, MVNO comprises of three components: visited MVNO, switching MVNO, and home MVNO. The sequence of events in foreign network is illustrated in Figure 16.6. Net business revenue (*BR*NET) for each service at MNO is defined as the ratio of product of average business revenue for each service in region *R* and tariff adjustment factor ($Tarrif_{\text{Adjustment\_Factor}}$) to the total number of MEUNs (*N*). BR_{NET} is defined as follows:

$$BR_{\text{NET}} = \left(\frac{BR_{\text{Avg,service}} \times R}{N} \right) \times Tariff_{\text{Adjustment\_Factor}} \tag{16.3}$$

16.3.1 Potential Business Strategies between MNOs, MVNEs, and MVNOs

Business model depends on the mutual contract between MNO, MVNE, and MVNO. Network enablers act as mediators between the network operator and VNO in home and foreign network. The primary factors affecting the quality of business are given as follows:

(i) Number of MEUNs requesting for services in licensed and unlicensed spectrum
(ii) Business services offered at higher prices due to increase in spectrum range
(iii) Business services offered at lower prices due to collaboration between MVNOs and MNOs
(iv) Density of originated and terminated calls at MVNO.

The compactness of MNO and MVNO can be effectively reduced by using network enablers. MVNEs [14] implement self-defined business schemes to attract the business interests of VNO and service points. MVNOs are identified by their respective access network numbers (ANs) and allocated radio spectrum. New business models with additional services are incorporated in existing framework to increase the number of potential MEUNs. MVNEs function as potential service access points to multiple MVNOs and enhance the service requirements of MVNEs. MVNEs enable user-centric services with MVNOs and backup services with intra-MNO domain or inter-MNO domain. MNOs assign spectral bandwidths to MVNOs [15], and further MVNOs can request the MNOs for additional radio spectrum and reconfigure the bandwidth (based on the density of MEUNs). Efficient channel management techniques improve the quality of voice and data rates with enhanced radio spectrum, nature of unguided media, and functional aspects of MVNO. Separate bandwidth is assigned for retail and commercial services. The number of retail services offered by MNO depends on the number of MVNOs and the cooperation factor with MNOs. For reliable MEUN services, an optimum number of VNOs maintain the required QoS and network performance. MVNE [16] uses schemas to advertise new business strategies for VNO and service providers. Consumer model [17] facilitates the MVNOs to acquire licensed radio spectrum from multiple MNOs and adapt a cooperative approach to share the licensed radio spectrum in business market. MVNO revenue ($\text{MVNO}_{\text{Revenue}}$) is a function of retail services, commercial services, net profit, and net loss. $\text{MVNO}_{\text{Revenue}}$ is defined as follows:

$$\begin{aligned} MVNO_{Revenue} = {} & f\left(MVNO_{Retail\_Services}, MVNO_{Net\_Profit}, MVNO_{Net\_Loss}\right) + \\ & g\left(MVNO_{Commercial\_Services}, MVNO_{Net\_Profit}, MVNO_{Net\_Loss}\right) \end{aligned} \tag{16.4}$$

MVNO net profit ($MVNO_{Net\_Profit}$) is a function of active users ($MVNO_{Active\_Users}$), data rate ($DataRate_{pkts/sec}$), and subscribed services ($MVNO_{Subscribed\_Services}$). $MVNO_{Net\_Profit}$ is defined as follows:

$$MVNO_{Net\_Profit} = \sum_{i=1}^{n} MVNE^{i}_{Active\_Users} \times DataRate_{pkts/sec} + \sum_{j=1}^{k} MVNO^{j}_{Subscribed\_Services} \quad (16.5)$$

MVNO net loss ($MVNO_{Net\_Loss}$) is a function of passive users ($MVNO_{Passive\_Users}$), allocated spectrum, and unsubscribed services ($MVNO_{Unsubscribed\_Services}$). $MVNO_{Net\_Loss}$ is defined as follows:

$$MVNO_{Net\_Loss} = \sum_{i=1}^{n} MVNE^{i}_{Passive\_Users} \times \text{Allocated Spectrum} + \sum_{j=1}^{k} MVNO^{j}_{Unsubscribed\_Services} \quad (16.6)$$

16.3.2 Performance Gain with SDN Approach

SDN approach enhances the functions of network virtualization by classifying the MVNO business model into the network plane, the filtering plane, and the pivotal plane. Network plane comprises of switches, routers, and gateways to control the network traffic. It monitors and controls the packet arrival rate to reduce congestion in the network. Authentication and validity of MEUNs are verified at filtering plane that comprises of MVNO firewalls. Pivotal plane comprises of access control, load balancing, and network virtualization. In SDN approach, VNOs protect unused license spectrum and divert the network traffic to underutilized spectrum resulting in energy-efficient network virtualization. SDN configures and improves the resource utilization in WiMAX and EDGE bearer services of 3G networks. With extended infrastructure and resources available, MVNOs offer voice, data, and multimedia services on behalf of MNOs. MVNO business markets in Europe and North America are much larger as compared to traditional mobile business services [18]. In retail business, MVNOs initiate the services or collaborate with MNOs that offer similar type of services.

16.3.3 Cooperation between MNOs and MVNOs

Business agreement involves sharing of licensed radio spectrum and network resources between MNOs, SPs, and MVNOs. Resource sharing can be symmetric (uniform resource distribution across virtual operators) or asymmetric (nonuniform resource distribution across virtual operators). MVNO pricing schemes vary with service type (high-speed data, multimedia live streaming, video conferencing, etc.) and business contract with multiple MNOs. In asymmetric resource allocation, the following business approach is considered: (i) MVNOs with high bargaining and investing capabilities bid for additional spectrum bandwidth and priority services, and (ii) MVNOs with low bargaining and investing capabilities bid for allocated channel bandwidth during nonpeak traffic conditions. MNO architecture emphasizes on leased infrastructure and licensed spectrum allocation from Internet service provider (ISP). In cooperative-based MVNO models [19], the bargaining strategies are prioritized with the

trade-off services of VNOs. Network traffic is a function of resource bargain factor and density of MEUNs for a given MNO domain. The min–max transaction cost is specified by MVNO controller. MVNO channel utility function ($\text{MVNO}_{\text{Channel\_Utility\_Function}}$) is low when the cooperation across MVNOs ($\text{MVNO}_{\text{Co-operation}}$) is low and the number of MEUNs is more than the threshold limit. $\text{MVNO}_{\text{Channel\_Utility\_Function}}$ is defined as follows:

$$\begin{aligned} &\text{MVNO}_{\text{Channel\_Utility\_Function}} = \text{low} \\ &\text{when } (\text{MVNO}_{\text{Co-operation}} = \text{low}) \text{ and } (\text{MEUNs} > \text{threshold}) \end{aligned} \tag{16.7}$$

MNVO performance gain is estimated using (i) quality of VNO voice and data services, (ii) MVNO utility functions, and (iii) MNO response time [20]. Based on MVNO service requirements and number of MEUNs, SDN approach enables the MNO to select the available spectrum range for wireless channels. SDN isolates the services of data and control plane [21] to (i) reduce ambiguity in decision making (such as selecting a channel with nonoverlapping bandwidth) and (ii) reduce collisions in the communication channel. This approach reroutes the network traffic through different channels and reduces the communication overhead. MVNO price tariff [22] is a function of structural and operational expenditure of MNOs. Greedy approach extends the support of flexible network capacity and services as required by MEUNs and current traffic conditions. MVNO capacity ($\text{MVNO}_{\text{Capacity}}$) is a function of aggregate bit rate ($\text{BR}_{\text{Aggregate}}$), location category ($\text{LOC}_{\text{Category}}$), and the number of active MEUNs ($N_{\text{Active\_Members}}$) per area A. $\text{MVNO}_{\text{Capacity}}$ [22] is defined as follows:

$$\text{MVNO}_{\text{Capacity}} = f\left(\text{BR}_{\text{Aggregate}}, \text{LOC}_{\text{Category}}\right) \times g\left(\frac{N_{\text{Active\_Members}}}{A}\right) \tag{16.8}$$

Greedy approach validates the current MVNO capacity to be at par with the previous capacity levels. The cooperating features of MNO and MVNO are given as follows:

(i) Integrating capabilities to synchronize with multiple BS
(ii) Controlling and coordinating with heterogeneous network to meet the predefined QoS parameters
(iii) Maintaining consistency and integrity services with MEUNs.

16.3.4 Flexible Business Models for Heterogeneous Environments

Virtual ad hoc network operators use network virtualization [23] that shares the licensed spectrum and create an ad hoc network for emergency services such as military monitoring, disaster management, vehicular monitoring, etc. Network interface is further extended to support the services of UMTS, GPRS, Wi-Fi, WiMAX, LTE-A, etc. Flexible business model [24] evaluates the mobile price tariffs, MEUN services, and device technology developments of the smartphone. Generic business model comprises of multiple marketing schemes such as E-commerce, M-commerce, and payment services for end-to-end vendors. The functional aspect of payment tariffs is based on the business relationship between MNOs, MVNOs,

and MEUNs. Table 16.2 describes various entities and their respective attributes used in existing business models. Distinctive features of actor and business model are given as follows:

(i) Interdependence between human, device specific, and business attributes
(ii) Cohesiveness between E-commerce and M-commerce applications
(iii) Revenue source and transactions performed by the active actors.

Business model [25] enhances the services of MNO based on the following features:

(i) MNOs define the business services and requirements for infrastructure network.
(ii) Service providers manage the resources between multiple MNOs.
(iii) List of MEUNs subscribed to corresponding MVNO.

Table 16.2 MVNO module type, access service, entity type and operational contract service [24] [27]

Module Type	Access Service	Entity Type	Operational Contract Service
Structural Module	Licensed Spectrum	Primary	Guaranteed bandwidth
		Secondary	Guaranteed bandwidth with refunds
	Un-Licensed Spectrum	Classified	Opportunistic access with pre-defined prices
		Regular	Opportunistic access with dynamic pricing schemes
	Networking Features	Wired or Cellular networks	Guaranteed or Opportunistic bulk access
		Wireless or Mobile networks	Guaranteed or Opportunistic bulk access
Financial Module	Wholesale Services	Value Configured Services	Guaranteed bandwidth
		Value Proposed Services	Guaranteed or Opportunistic bulk access
	Retail Services	Operator defined or branded	Guaranteed or Opportunistic bulk access, Region or Service based
		User specified	Opportunistic and Service oriented
Security Module	Threat Handling	Firewalls and Proxy Servers	Included with operational charges
	Authorized Access Control	Multiple purpose user identities	Included with operational charges

SDN [26] approach to backhaul MNO systems extends the support of LTE and LTE-A networks. Backhaul network pool and spectrum resources support uninterrupted QoS to potential, authentic, and licensed MEUNs. High-speed networks deploy micro and macro BS at various locations in mobile network. The spectral ensemble of current market trends [27] represents the existing business models for efficient bandwidth and fair connectivity with MEUNs. The spectrum access for mobile business model is given as follows:

(i) MNOs access the primary spectrum.
(ii) VNOs access the secondary spectrum through network enablers.
(iii) MEUNs function as ternary spectrum access providers.

MVNO reservation is based on license registration and regulation schemes subscribed to MNOs. A well-defined pricing scheme provides guaranteed and consistent services to MEUNs. The business approach in hierarchical spectrum market supports risk-return trade-offs and flexible pricing schemes to sustain the market growth from local and global competitors.

16.4 MVNO Developments in 3G, 4G, and LTE

Increasing competition in MNOs facilitates different pricing schemes for individual and group members based on content-oriented services. The limitations of MVNO business models are given as follows:

(i) Inaccessibility of existing cellular and Wi-Fi networks
(ii) Authentication process for active sessions
(iii) Nonflexible Mobile IP services to MEUNs
(iv) Sustainable services for high-speed mobile Internet.

This section elucidates various techniques to improve the MVNO business model based on mobility support, multiple interfaces, and SDN approach to 3G, 4G, and LTE mobile networks.

16.4.1 MVNO User-Centric Strategies for Mobility Support

In MNO deployment phase, the infrastructure is configured with predefined set of rules between the vendor, bidder, and auctioneer. SDN metrics are configured to incorporate the updates received from MVNO. Negotiation schemes for object migration access [7] support resource flexibility and mobility services. Negotiated network resources meet the current requirements of MEUNs and estimate the future requirements. A prototype of middleware architecture is designed to support dynamic MEUNs with loosely coupled domains that function as the federation of grid resources.

Virtualizing personal and home networks [28] reveal the issues associated with Third Generation Partnership Project (3GPP), International Telecommunication Union (ITU), and Universal Mobile Telecommunications Systems (UMTS). Mobility in heterogeneous nodes establishes connectivity using pico, micro, and macro resources with increasing order of

coverage and coordination levels. For a given application scenario, MEUNs can be loosely or tightly coupled between the home and foreign network. Technoeconomic evaluation [29] measures the net value of cash flows into the system over a period of time, and the cost evaluation model measures the current trends in mobile business market. Periodically, the discount rates offered to customers (for audio, video, Internet, etc.) and the rate of return are evaluated in this method. User-centric services [30] are the best connected services in the MVNO business model.

Virtual private mobile network operator (VPMNO) [31] is a three-phase functional model that ensures virtualization and subdivisive aspects of network management. VPMNO enhances the addressing mechanism and reduces the complexity in mobile network infrastructure. VPMNO further extends the functionality of MVNO business model by service replication and partitioning of MEUNs across MNOs. The unused bandwidth known as backbone bandwidth increases the business opportunities in MNO.

16.4.2 Management Schemes for Multiple Interfaces

Network resource manager (NRM) [32] allocates the bandwidth and manages services to meet the specified QoS configured by MNO. The business models are primarily categorized as follows:

(i) Radio resource management scheme that enables coverage services and network bandwidth
(ii) Service management scheme that meets the requirements of subscribed MEUNs with a wide range of service packages

Business management framework [33] uses incremental method from the physical layer (radio management) to the application layer (trusted services) to alter the decision-making process as per the demands of MEUNs. 3G MVNO [34] supports mobile bearer services such as 2G, UMTS, LTE, LTE-A, etc. in European markets. Network operators are categorized into rural and urban area networks based on the number of licensed MVNOs and the corresponding MEUNs associated with MVNOs. The business model with utility functions [35] estimates the gains of individual operations and determines the best utility package for MVNOs. MVNOs are grouped into clusters [36] with common aspects such as business development strategy, global scope, and application services. SDN-based spectrum allocation techniques dynamically distribute [37] the resources in MVNO business model. The collaboration between different stakeholders is primarily based on allocated channel frequency and rate of packet transmission. Due to increasing potential services of the Internet and LTE [38], mobile network virtualization explores multiplexing and multiuser diversity gain for a set of MVNOs. Wireless infrastructure [39] is configured with innovative business market models by using the MIMO-enabled MEUNs.

16.4.3 Enhancing Business Strategies Using SDN Approach

SDN configures the distributed virtual network and achieves price tariff trade-off for the services subscribed by MEUNs. Wide-area virtual service migration [40] supports adversaries in dynamic traffic conditions. VNO [41] categorizes the virtual components as follows:

(i) **Link Virtualizers**—Support virtual links that share the physical link. Virtual links define the tags (explicit and implicit) with allocated time slots and bandwidth.
(ii) **Node Virtualizers**—Differentiate the network protocols other than IP. Node virtualizers configure, manage, monitor, and resolve the network complexities in an active session.

MVNOs support multiple operating systems with common interface services and mapping procedures. Optimal prioritization of time schedulers and generic bandwidth framework [42] enhances the performance of MVNOs. SILUMOD [43] implements node mobility and ignores virtualization. The interface components support concurrent heterogeneous operators and subscribers. MEUNs elect a domain-specified language that exactly maps the mobility services in an active session. After initialization, the MEUNs invoke virtual operations that are controlled by VIRMANEL engine. This helps to locate the position of MEUNs in home or foreign network. The price tariffs defined by MNO services and their respective economic consequence on MVNO [44] are evaluated to estimate the performance of MEUNs in global market. This business model further optimizes the MNO service and increases the profit margins in local and global markets. VNO as cloud with data-centric services strengthens the resource pool spread across the network for voice and data services.

Operator migration for mobility-driven processing [45] extends the infrastructure of MVNO to support cloud computing and fog networking resources for end-to-end delivery services. This business model enhances the performance by supporting the network operators to use partial bandwidth during (a) peak traffic duration and (b) migration period. Spectrum sharing schemes and performance of MVNO are based on the pricing schemes [46] of the femtocell market.

16.5 Cognitive MVNO

16.5.1 Cognitive Radio Management in MVNOs

Cognitive radio management (CRM) resolves the functional differences in heterogeneous multiradio systems, coordinates with MVNOs, and efficiently utilizes the resources in multiuser subsystem. CRM comprises of tight coupling and coordination between the physical layers and software defined radio attributes of MVNO. MNOs use dynamic prioritizations to support multioperational schemes. Hence, multiagent MNOs are used for data sharing and resource allocation. Enhancements in MVNO design [47] support UMTS and WCDMA network with roaming in MEUNs and network consistency in heterogeneous systems. Based on the number of offered services, VNOs act as single or multiple carriers. High pricing schemes are invoked by dedicated carrier signals that serve multiple VNOs in rural and remote areas. Low pricing schemes are invoked by fixed capacity carrier signals that offer affordable pricing schemes to a large number of MEUNs. Tolerant levels of MVNO servicing scheme are a function of the number of active channels and service load. MVNO service rate ($\mathrm{MVNO}_{\mathrm{Service\_Rate}}$) for VNO is the ratio of load offered ($\mathrm{MVNO}_{\mathrm{Load\_Offered}}$) and channel capacity ($\mathrm{MVNO}_{\mathrm{Channel\_Capacity}}$). $\mathrm{MVNO}_{\mathrm{Service\_Rate}}$ is defined as follows:

$$\mathrm{MVNO}_{\mathrm{Service\_Rate}} = \frac{\mathrm{MVNO}_{\mathrm{Load\_Offered}}}{\mathrm{MVNO}_{\mathrm{Channel\_Capacity}}} \tag{16.9}$$

MVNOs extend their consistent services and cooperate with other operators to form a grid of available resources. MNO accumulates the statistics of communication link and, if possible, reduces the network bandwidth. MVNO lookup table consists of the following attributes:

(i) Number of MEUNs associated with MVNO
(ii) Available resources
(iii) Network load
(iv) Available bandwidth
(v) Average energy required for maximum number of transactions.

New service requests from MEUNs can be accepted or rejected based on the service priority and network traffic conditions [48]. Cognitive MVNO (C-MVNO) [49] with OFDMA technique for downlink criteria supports the increasing demand of high-speed data transmission. Instant decisions based on available bandwidth, existing pricing schemes, and network traffic conditions are used in this model. The user requirements are broadly classified into service set, pricing schemes, and validity period. This approach becomes more realistic by monitoring the behavior of primary spectral management schemes (such as the spectral usage and time delays in packet transmissions) and decides the secondary spectral management schemes with proper pricing schemes. MEUN data packets that arrive at frame windows with overlapping time durations result in collision. This triggers a false alarm ($MVNO_{False\_Alarm\_Capacity}$) since the actual collision might have occurred in previous frame window that is much prior to the current transaction. The number of MVNO packets that were not detected ($MVNO_{Missed\_Detection}$) due to false triggering, increases the operational cost of MVNO. MVNO operational cost is defined as follows:

$$MVNO_{Operational\_Cost} = \begin{cases} \text{high} & \text{when}\left(MVNO_{False\_Alarm\_Capacity} \,\&\, MVNO_{Missed\_Detection}\right) \Rightarrow \text{low} \\ \text{low} & \text{when}\left(MVNO_{False\_Alarm\_Capacity} \,\&\, MVNO_{Missed\_Detection}\right) \Rightarrow \text{high} \end{cases} \tag{16.10}$$

This method certainly reduces the complexity as compared to the existing online pricing schemes in MVNO business market.

16.5.2 Cognitive and SDN-Based Spectral Allocation Strategies in MVNO

The price tariffs are assigned to MVNO with variations in radio spectrum allocation. Low-price tariff depends on wholesale prices offered by MNO and the density of MEUNs. High-price tariff is limited to bandwidth and used in high-speed commercial applications. MVNOs are adaptive to unattended market services and extend their services to widespread market. MVNO performance can be improved by using cognitive and SDN methodologies in interference mitigation and MNO switching. Based on the number of MEUNs and respective services, MNO partitions the allocated spectrum into standard and optimized services. The subscriber services are highlighted as follows:

(i) **Standard Subscriber Services (SSS)**: This service by MVNO includes allocation of premium channel bandwidth for short duration in low network traffic conditions. This service supports multimedia applications for MEUNs.
(ii) **Optimal Subscriber Services (OSS)**: This service by MVNO includes allocation of premium channel bandwidths for maximum time duration. Licensed MEUNs with allocated spectral resources are given high priority and achieve maximum throughput rate. The pricing tariffs for optimal services will be higher in licensed services as compared to unlicensed services.

Discrete MVNO service optimization (MSOP) is a function of:

(i) Authentic MEUNs associated to MNO
(ii) Set of services (SoS) enabled to MEUNs
(iii) Data rates open to MEUNs
(iv) Set of business relations to estimate the cost of service.

16.6 MVNO Business Strategies

MVNO business model comprises of generic services, services available at home domain, service requests by heterogeneous MEUNs, and additional service requests by MVNEs. MVNEs purchase the licensed spectrum from MNOs and coordinate the services with MVNOs.

Depending on the availability of MVNE services, appropriate tariff plans are facilitated to MVNOs and group MVNOs as illustrated in Figure 16.7. MVNOs implement business strategies based on market analysis, service requests by MEUNs, and degree of coordination between multiple MNOs. Table 16.3 highlights the MVNO service model and their respective features.

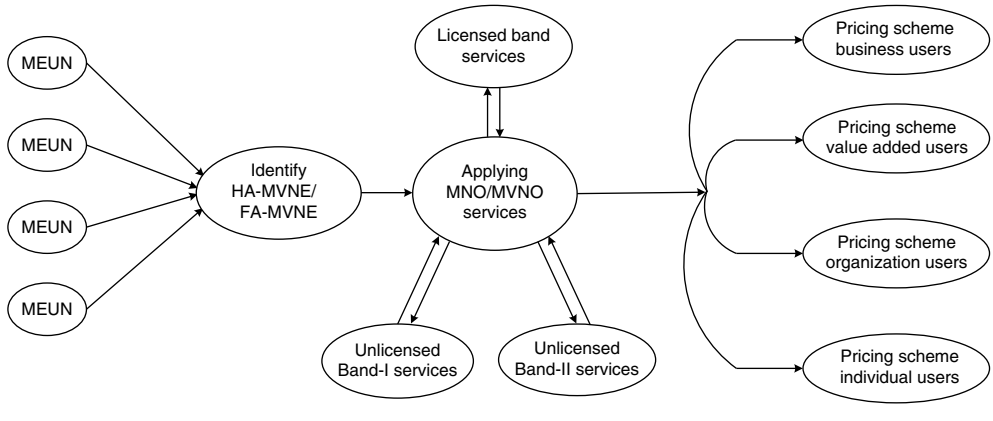

Figure 16.7 Business model of mobile virtual network operator.

Table 16.3 MVNO service model and features

Service Model	Feature
Business Service Model	Business MVNO
	M2M MVNO
	Advertising MVNO
	Ethnic MVNO
Consumer Service Model	Value added services
	customer support
	Billing Process
	Flexible Packages
	Tariff Bundles and Packages
	Audio, video and text
Enhanced Service Model	Intelligent Network
	Next Generation Intelligent Network
	(voicemail, call forward, roam forward, VPN)
Application Service Model	Voice
	Data
	SMS
	Multimedia
User Supportive Service Model	Adaptable with GSM, CDMA, WiFi and WiMax technologies
	Time-based Tariff packages
	Group Tariff packages

16.6.1 Services and Pricing of MVNO

The emerging technology in WiMAX, Wi-Fi, WPAN, etc. significantly increases the role of MVNOs as trusted mediators. MVNOs offer intermodular and intramodular services. Intermodular MVNO (IE-MVNO) controls and manages the local power resources, spectrum allocation, throughput rate, and coordination with intermodular roaming services for authentic MEUNs. Intramodular MVNO (IA-MVNO) coordinates with IE-MVNOs and its subregions. The pricing tariffs for home network and foreign network are formulated as follows:

$$Pricing_{Home} = f^{Home}_{Tariff\_Function}\left(MNO_{Home}, MVNO, ServiceType_{Home}, Duration\right) \quad (16.11)$$

$$Pricing_{Foreign} = g^{Foreign}_{Tariff\_Function}\left(\sum_{i=1}^{n} MNO^{i}_{Foreign}, MVNO, ServiceType_{Foreign}, Duration\right) \quad (16.12)$$

The pricing tariffs are based on offered load, low S/N ratio, and MEUN service set. Dynamic pricing schemes are based on the level of services and resource allocated by MNOs. The resource utilization schemes are congestion sensitive and support reliable services to MEUNs. Figure 16.8 illustrates various pricing schemes and pricing tariffs used by MVNO business model. The pricing schemes are categorized as long term and short term, and the pricing tariffs vary with service set package across the MVNO business market.

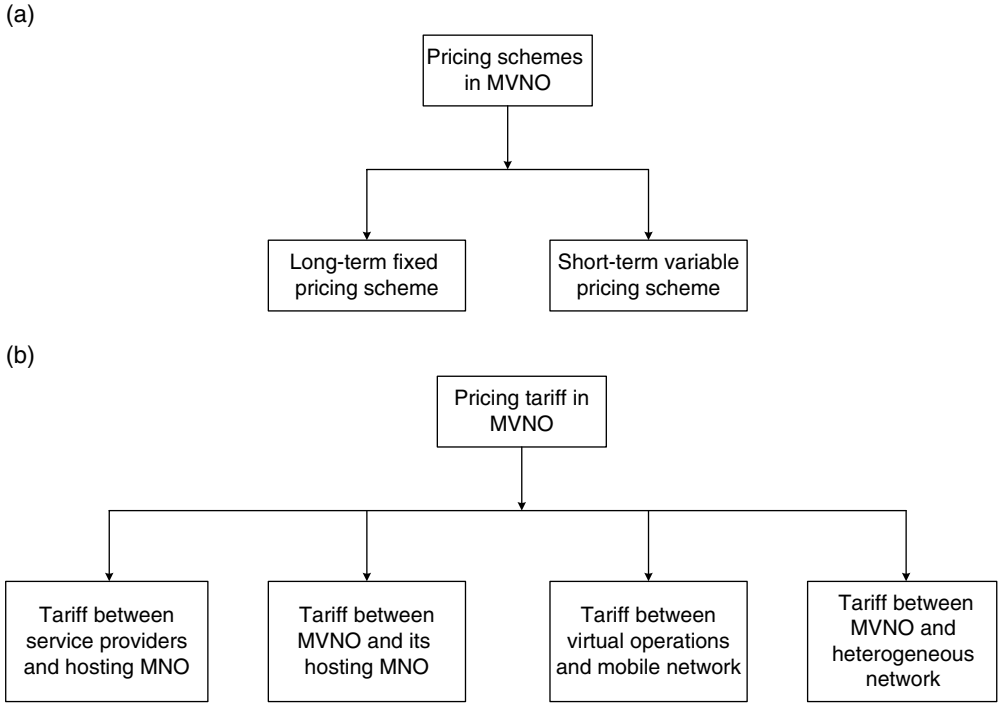

Figure 16.8 Pricing schemes and tariffs in MVNO business market. (a) Pricing schemes and (b) Pricing tariffs.

16.6.2 Resource Negotiation and Pricing

Resource negotiation is a function of number of hops, QoS within each hop, and degree of congestion. In Resource Negotiation and Pricing (RNAP) scheme [50], the MEUNs negotiate with MNOs and select (i) the resource set and (ii) the corresponding service set. Long-term fixed pricing scheme does not support dynamic resource allocation, and it leads to resource underutilization during abrupt and random traffic conditions. The attributes of RNAP pricing tariffs are: (i) MEUN set of services, (ii) time duration, and (iii) allocated spectrum bandwidth. The resources are distributed across MEUNs for high-speed audio, video, and Internet applications. In resource-constraint conditions, the video applications are given low priority because of inconsistent and intermittent data streaming conditions.

16.6.3 Pushover Cellular and Service Adoption Strategy

MENO supports voice services that can be extended to video conferencing using 3G, LTE-A, and 4G cellular networks. Military, marine, railway, and airline services use push-to-talk (PTT) services that function in full-duplex mode. This identifies the intruders in restricted areas like forest, valley, underground, underwater, etc. PTT uses very-high-frequency (VHF) signals to trace the recipient radio. Pushover cellular (PoC) [51] provides a standard platform

and offers digital packet radio service through Internet protocol and improves the resources utilization factor between the vendors, MNOs, and MEUNs. MEUN services are upgraded using the extended MVNO framework and value-added services. Service points and MVNOs are given priority over the network operators to design the intended servicing schemes as per the MEUN requirements and pricing tariffs.

16.6.4 Business Relations between the MNO and MVNO

Exponential increase in MEUNs and high-speed data services increase the competition in MNO business market. User-centric MVNO approach increases the efficiency in mobile network and establishes the assured business relations with MNO. MVNO service packages include SIM card with prepaid services, postpaid services, voice, video, Short Message Services (SMS), Internet, and multimedia services. MVNO [52] services have significantly improved by offering stable and persistent amenities for MEUNs. Based on MEUN service history and emerging services, MVNOs estimate the user demands and extend the services to MEUNs. The demand for secondary spectral subscribers is efficiently priced [53] at optimal sensing and service schemes. Licensed radio spectrum allocated for primary users are fragmented into leased schemes that are valid for short and longer durations. Pricing tariffs are based on network demand, traffic conditions, number of primary users, number of secondary users, and service package set. This technique supports equal channel utilization across the MEUNs in mobile network. This architecture extends the feature of cellular and mobile network and supports the signaling services of location update, and connectivity between MEUNs and MNOs. Return on investment (ROI) [54] utilizes the unused shared spectrum region and enhances the resource utilization factor for existing MEUNs.

MVNOs reduce the risks in business support system [55] (flat and horizontal architectures) and accommodate high-speed network services in LTE-A and 4G systems. The emerging service agreements are classified and addressed by the cloud system. MVNO-connected [56] services are classified into full mode, multimode, and best connected mode based on packet switching, voice over LTE, and Evolved Packet Services (EPS). Business relation between the primary and secondary license holders in shared radio spectrum [57] enhances the services of existing economic policies. Marketing model is based on the service mitigation schemes between the bidders, the auctioneers, and the buyers. In the first phase, the bidding process is allowed by MVNOs, and in the second phase, the bidder fixes the unit price and assigns it to MVNOs. The business model emphasizes the following: (i) rational behavior between MVNOs, (ii) data distribution between MVNOs, and (iii) data integrity. The business model analyzes the revenue gain between the initial investment and final returns for primary and secondary radio spectrum services.

16.7 Conclusions

MVNOs are the primary contenders in the existing industry of mobile communication network. Due to available network resources and advanced infrastructure, MVNOs facilitate high-speed mobile services with reliable user-centric services at low-price tariffs as compared to MNOs and service providers. MVNOs adapt business strategies to extend the basic bearer

services from GSM and UMTS to the latest LTE-A and 4G networks. Cognitive and SDN techniques in MVNO business models enhance the services of MNO, MVNE, and MVNA. This approach further facilitates extended services to MEUNs. This chapter elucidates mobile market policies and business relations between MNOs and VNOs. For enhanced services, MVNO business models use localized resource relocations such as the femto, pico, and micro BS for small-scale and large-scale mobile networks.

16.8 Future Directions

Future directions include enhance MVNO services that comprise of research development toward: (i) fault-tolerant MVNO (failure at one MVNO can disrupt the transactions of other MVNOs), (ii) time slag (the processing conditions and operational differences between heterogeneous MVNOs), (iii) cochannel interference with other broadband services, (iv) resource allocation and management in dynamic traffic conditions, (v) violations of predefined business contracts by MVNOs, and (vi) conflicts ascended across MVNOs.

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