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Estimating the deployment costs of broadband universal service via fiber networks in Korea

Hyeongjik Lee *, Seonkoo Jeong, Kwanghee Lee

Technology Policy Research Division, Electronics and Telecommunications Research Institute, 218 Gajeong-ro, Yuseong-gu, Daejeon, 34129, South Korea

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A B S T R A C T

While both broadband itself and its speed are becoming increasingly important in all spheres of society, the high cost of providing broadband as a universal service at high speed still raises a fundamental question: Is the introduction of the universal service obligation (USO) necessary? Therefore, the introduction of universal broadband service at 100 Mbps in Korea in 2020 could be a meaningful case study to evaluate the necessity of broadband USO. This study proposes an estimation model of the costs of providing universal broadband service in Korea and assesses whether the introduction of the broadband USO was appropriate in Korea. Since the proposed model was based on the bottom-up (BU) approach, which establishes an efficient network using the latest technologies, the estimated cost of providing universal broadband service nationwide in Korea is accurate and reliable. The main findings are threefold. First, the total cost of providing broadband USO at 100 Mbps through the fiber-to-the-home technology was about 1.1 trillion Korean Won. Since this is a relatively small amount compared with previous evaluations, it could be recovered within a reasonable period from the monthly broadband fee that subscribers pay. Therefore, the result supports the introduction of universal broadband service in Korea. Second, there was no significant difference in the average cost per building for broadband USO between 50 Mbps and 100 Mbps; thus, the Korean government's decision to set the broadband speed for broadband USO at 100 Mbps was reasonable, at least from a cost perspective. These results imply that developed countries with relatively high broadband penetration, in particular, could consider providing universal broadband services of at least 50 Mbps by fiber-based technologies. Lastly, although the total cost of offering fiber-based universal broadband services in Korea was acceptable, the government could also consider including wireless access technology as a technological alternative to reduce the costs of the USO policy.

1. Introduction

With the increasing importance of broadband in all spheres of society, the number of countries designating broadband as a universal service, or those intending to do so, has also increased. In late 2018, the Korean government decided to offer universal broadband service at 100 Mbps from 2020. Although Korea has been the leading country in broadband penetration over the last

* Corresponding author.
E-mail addresses: hyeongjiklee@etri.re.kr (H. Lee), skj0102@etri.re.kr (S. Jeong), lkh@etri.re.kr (K. Lee).

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decades[1] (OECD, 2019; Picot & Wernick, 2007), a significant number of buildings had no access to high-speed broadband in rural areas as of May 2018.[2] One surprising aspect of the government decisions is the download speed of 100 Mbps for the broadband universal service obligation (USO), which is perhaps the highest speed for USO worldwide.[3] The government's offer could not be regarded as excessive and challenging, considering that 85.5% of domestic broadband subscribers have already used at least 100 Mbps high-speed fixed Internet services. However, it is also evident that the cost of deploying a broadband network has grown sharply with the increase in the speed obligation (Stocker & Whalley, 2019),[4] even though broadband speed has a positive impact on the whole economy (Schneir & Xiong, 2016; Stocker & Whalley, 2018). Therefore, the high cost of providing broadband as a universal service at high speed could raise a question: Was the introduction of the USO in Korea appropriate?

Some might argue that the universal service level depends on a political rather than a technocratic decision (Oughton, 2016). However, governments should still make reasonable and appropriate policy decisions on USO through a comprehensive process, including both qualitative and quantitative analyses. In 2016, for example, the UK telecommunications regulator Ofcom announced broadband USO consultations, including quantitative studies, on the broadband speed obligation of 10 Mbps and the total cost for the broadband USO (Stocker & Whalley, 2019). The broadband USO policy was then finally decided in 2017 after a review of stakeholders' opinions. In the case of Korea, the Ministry of Science and ICT, the telecommunications regulator, established a study group for broadband USO, consisting of regulators, stakeholders, and professionals, in 2017, and announced the introduction of the broadband USO in Korea based on the study group's recommendations. The broadband USO was finally introduced in Korea following a revision of the regulations in 2019 after a review of the stakeholders' opinions. Estimating the cost of establishing networks for broadband USO nationwide, which is one of the quantitative analyses employed in the government's decision-making process, would help the government to decide, for example, whether to introduce broadband USO, the speed level of the broadband USO, and how to operate the USO policy. A cost estimation could also contribute to assessing the appropriateness of the government's decisions from a cost perspective. For example, the European Union decided, in both 2006 and 2008, not to designate broadband as a universal service considering the cost implications (Bogojevic, 2012). In the Korean case, assessing whether the 100 Mbps USO is acceptable in terms of cost could provide meaningful implications for the government's USO policy operation.

The purpose of this paper is to propose an estimation model of the costs of providing universal broadband service in Korea and to assess whether its introduction in Korea was appropriate. A USO policy analysis should focus on accurately estimating the incremental total costs subject to the current broadband coverage. Therefore, a reasonable estimation of costs using a universal service operator's past investments or future investment plans is not appropriate. The proposed model, which is based on the bottom-up (BU) approach, allows us to calculate the optimal incremental network costs of establishing an efficient network using the latest technologies. The model first designed two different fiber-based broadband access networks, namely, fiber-to-the-home (FTTH) and fiber-to-the-distribution point (FTTDP), at 23 sampled areas in Korea representing the whole country. It estimated the additional costs of deploying these broadband USO networks for different scenarios of specific access technologies (e.g., FTTH, FTTDP, or least-cost technology), broadband speed (e.g., 20 Mbps, 50 Mbps, 100 Mbps), and other elements. Although previous literature addressed issues of whether to implement the broadband USO policy and whether the measure would encourage broadband development, the installation cost of access networks for universal broadband service has not been sufficiently considered through quantitative analysis. This study is perhaps the first attempt to quantitatively assess the cost of providing the universal broadband service in Korea; thus, it could be entirely meaningful for academia and policymakers.

The rest of our study is composed of four sections, as follows. Section 2 presents a literature review about universal broadband service, including cost estimations for the service. Section 3 describes the cost estimation methodology for the universal broadband service, including geo-types, network architectures, and the cost model. Section 4 presents the estimation results for the universal broadband service in Korea—average investment per building for providing universal broadband service and the total cost for achieving 100% coverage through the broadband USO for different scenarios. It also discusses the results and policy implications. Finally, Section 5 presents our concluding remarks.

2. Literature review

2.1. Previous studies on universal broadband service

Universal service is a telecommunication service that every citizen can access and use at a reasonable price (Batura, 2017). The telecommunications act in Korea has also defined universal service along the same lines. Up until now, the fixed telephone service through the public switched telephone network (PSTN) has been designated as a universal service, and several countries have begun to

[1] For example, according to the OECD broadband portal, as of June 2019, Korea's broadband penetration rate is the fifth-highest among OECD countries, and the fiber-based broadband penetration rate is the highest (OECD, 2019).

[2] In December 2018, the government stated that domestic ISPs cannot provide fixed broadband services to about 800,000 buildings in Korea because of low profitability despite consumer requests.

[3] The highest speed obligation for the broadband USO is currently 10 Mbps in countries that introduced broadband USO, including the United States, Spain, and the United Kingdom. Meanwhile, among the countries planning to introduce the broadband USO, Canada is reportedly reviewing its decision to designate the broadband USO at 50 Mbps.

[4] For example, Stocker and Whalley (2019) reported, based on a technical note by Ofcom, that it would cost £1.1 billion to provide broadband connections at 10 Mbps and £1.9 billion at 20 Mbps in the United Kingdom.

include broadband within the scope of universal service. In most cases, the universal broadband service has been interpreted as a fixed service through wired copper/fiber connection lines. However, from the principle of technology neutrality, some also argue that the scope of universal broadband services could be expanded flexibly and comprehensively considering the sharp changes in technology and consumer preferences and usage patterns (Alleman et al., 2010). For example, the Finnish government included the mobile broadband service within the scope of universal broadband service in 2010, which helped it achieve its broadband penetration goals (Benseny et al., 2019).

Most previous literature analyzed whether broadband should be considered a universal service and whether USO could contribute to broadband development, especially in developed countries. To first consider the positive aspects of universal broadband service, Bogojevic (2012) suggested that the broadband USO policy, despite the high cost involved, could be used as a strategy to encourage broadband deployment. The author also mentioned that broadband had generally been evaluated as a universal service in Europe, except for the intervention cost criteria. Bohlin and Teppayayon (2009) also argued that while broadening the scope of universal services to include broadband, it is important to note that a cautious comprehensive approach to include broadband, that the under the principle that universal service is a dynamic and evolving concept, it is more important to respond to changes in the needs and expectations of consumers. These authors also insisted in other studies (Teppayayon & Bohlin, 2010) that universal broadband service does not always distort market competition due to a complementary relationship rather than a confrontational relationship between the universal service regime and the market competition. However, they suggested that the universal service scheme could need to be redesigned to prevent any possible competition distortion if universal broadband service is to be appropriately implemented.

As for the negative aspects of universal broadband service, Falch and Henten (2009) suggested that the broadband penetration rate is continuously increasing in Europe, despite differences between countries as well as between cities and rural areas, even as domestic Internet service providers (ISPs) are engaging in fierce competition over various access technologies. Thus, they argued that the introduction of the broadband USO is not sufficiently warranted. Alleman et al. (2010) also pointed out that the designation of broadband as a universal service should be carefully considered because the USO concept can cause distortions in the economic efficiency of the broadband market. Furthermore, Batura (2017) insisted that the broadband USO policy cannot be effectively used for broadband development and that the broadband coverage goals can be more effectively achieved through other policy instruments.

In addition, some previous studies on universal broadband service have not considered the necessity of introducing broadband USO. For example, Boik (2017) analyzed users' adoption patterns and substitution of broadband services in North Carolina. He found that the broadband USO policy users did not adopt universal broadband service as a result of the USO policy, but rather switched between high-speed fixed broadband and the low-speed service. Stocker and Whalley (2019) qualitatively analyzed responses to the broadband USO consultation by Ofcom and suggested policy implications for the government's operation of the broadband USO policy in the United Kingdom.

In summary, as shown in Table 1, previous studies have investigated the necessity of broadband USO from various aspects, including the relationship between the broadband USO policy and broadband development, especially in the developed countries. However, the rationale of their arguments seems to be relatively weak considering the lack of quantitative analyses of the universal broadband service, including total cost estimations for providing the service.

2.2. *Previous studies on estimating the cost of providing broadband services*

Most recent cost assessments of the broadband service offering analyze the establishment of broadband networks in rural areas where the broadband penetration rate is relatively low. First, Schneir and Xiong (2016) estimated the total costs of providing broadband services at 30 Mbps or 100 Mbps, the targets set for 2020 according to the European Digital Agenda. Their results show that the cost of deploying broadband is 80% higher on average in non-urban or rural areas compared to urban areas, and is the highest for

Table 1
Previous studies on universal broadband service.

Previous study	Pros and cons of universal broadband service	Relationship between universal broadband service and broadband development
Falch and Henten (2009)	Opposition (Unnecessary)	Broadband development could be achieved through market competition without imposing universal service obligations.
Bohlin and Teppayayon (2009)	Assent (Necessary)	Some kind of government intervention, including broadband as a universal service, could be necessary for broadband development in rural and remote areas, due to the limitation of market-driven policy.
Teppayayon and Bohlin (2010)	Assent (Necessary)	The relationship between universal service regime and market competition is complementary rather than confrontation.
Alleman et al. (2010)	Neutral	No specific comments
Ragoobar et al. (2011)	Assent (Necessary)	USO could boost broadband deployment in rural areas in the United Kingdom.
Bogojevic (2012)	Assent (Necessary)	The addition of broadband within the scope of universal service could be a strategy to encourage broadband development.
Batura (2017)	Opposition (Unnecessary)	The broadband USO policy in Europe is unlikely to be effective for broadband development.
Boik (2017)	Neutral	Households do not unconditionally adopt universal broadband service and could choose low-speed instead of high-speed broadband from a cost perspective.
Stocker and Whalley (2019)	Neutral	No specific comments

the FTTH technology and the lowest for Very high-bit-rate Digital Subscriber Line (VDSL).

Second, Oughton (2016) calculated the total cost of providing broadband over fiber connection lines to satisfy the "needs" of the United Kingdom. The author showed that the cost of deploying broadband networks in urban areas, which account for 70% of the whole United Kingdom, would be between £14.1 and £17.0 billion. In contrast, the deployment cost for non-urban or rural areas, accounting for the remaining 30%, would range between £13.7 and £15.8 billion. He also suggested that technologies such as fiber-to-the-distribution-point (FTTDP) would be acceptable in the short term because of the high cost of providing broadband services using the FTTH technology.

Finally, Ioannou et al. (2020) estimated the net present value (NPV) of establishing 30-Mbps broadband networks using fixed wireless access (FWA) technologies based on FTTDP, VDSL, and Long-Term Evolution (LTE) in the rural areas of Europe. According to their analysis, LTE-based FWA could be a feasible and cost-effective solution for providing broadband services at 30 Mbps in rural areas.

In summary, although the studies mentioned above could provide meaningful implications for universal broadband service in non-urban or rural areas, they did not adequately analyze the total costs of providing universal broadband service. Therefore, their results seem to have limitations for validation of the broadband USO policy.

2.3. Previous studies on the broadband USO in Korea

Several domestic scholars have focused on the broadband USO in Korea. First, a few studies examined the necessity of the broadband USO in Korea before the government decided to introduce the service. For example, Lee and Lee (2015) investigated whether broadband could be regarded as a universal service based on the standard criteria established in Europe and suggested that the necessity of universal broadband service was relatively low. By contrast, Jung and Kim (2017) insisted on universal service because broadband could not be provided to all the households despite the competitive market in Korea. Second, a few studies suggested policy strategies for the broadband USO in Korea after the government announced its introduction. Ko et al. (2019) proposed some points for consideration, including the scope of the USO (nationwide or regional), the speed, and the funding method, for successful operation of the broadband USO policy.

However, the studies mentioned above are deficient in that they are not sufficiently backed by quantitative analyses. Although they examined the necessity of universal broadband service in Korea, their arguments about the cost requirements for the broadband USO were not supported by explicit analysis. They emphasized the need of high-quality universal broadband service, but could not justify the additional investment required through quantitative analysis. In contrast, this study estimates the installation cost of the nationwide network for universal broadband service, thereby helping the government to decide, for example, whether to introduce the USO and what speed to offer.

2.4. Summary of the literature review

In summary, the literature review shows a lack of adequate quantitative analysis to estimate the installation cost of broadband access networks for universal service. Several authors have examined whether the broadband USO policy should be implemented and whether it would encourage broadband development. Other authors have estimated the cost of providing broadband in rural areas outside the ambit of broadband USO. However, studies on the cost of providing universal broadband service in Korea are scarce. Therefore, this study is meaningful in that it is the first attempt to quantitatively calculate the cost of introducing the broadband USO in Korea through a novel method.

3. Cost estimation methodology for providing universal broadband service in Korea

This section describes the procedure employed, the geo-type setting, the network architectures used, and the proposed cost model to estimate the costs of providing universal broadband services in Korea.

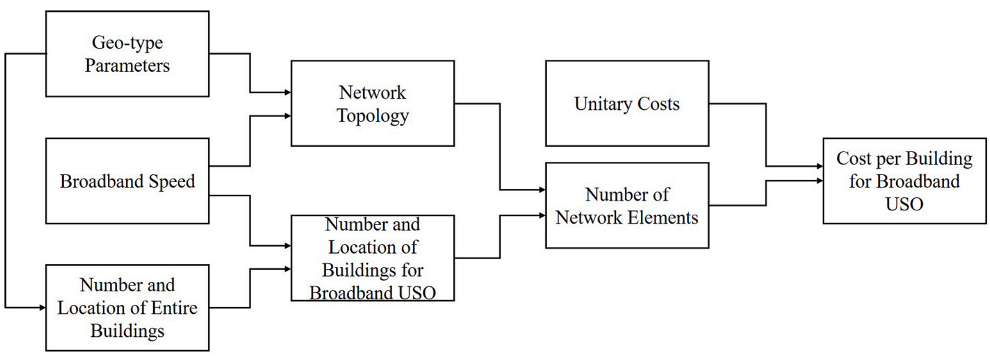

Fig. 1. Procedure for the cost estimation of the universal service offering (USO).

3.1. Cost estimation procedure

The procedure employed for estimating the costs of providing universal broadband services in Korea is as follows, as shown in Fig. 1. First, we classified the Korean territory into the nine geo-types and selected 23 sample areas representing each geo-type in Korea. Section 3.2 describes the geo-type setting in Korea. Second, we defined the network topology based on the geo-types to prepare a network design for the universal broadband service of each type. Section 3.3 explains the network architecture selected from among several possible technology alternatives. Third, the number and location of three types of buildings (all buildings of the country, buildings providing broadband currently, and buildings without broadband) were derived as input data for each sample area. Considering that single broadband access to a specific building enables all of the households in the building to use broadband services, a building was more suitable as a unit of analysis than a household. We obtained specific information on buildings at each sample area as of May 2018 from the national broadband coverage data submitted by all domestic ISPs. Fourth, using the data mentioned above, we redesigned the broadband access network of each sample area and calculated the number of network elements established in each sample area. Lastly, as shown in Fig. 1, the cost per building was estimated based on the total additional cost to achieve broadband coverage of 100% in each sample area. Section 3.4 explains the cost model with other input parameters employed, including the unitary costs of network elements. The input information was obtained from the domestic ISPs and some professionals interviewed.

3.2. Geo-type approach

Redesigning broadband networks in all regions of the country seems the ideal approach, but it is an impossible task, as well as an inefficient method to estimate the costs of providing universal broadband service. Therefore, instead of redesigning the entire country, we chose an efficient approach to estimate the costs for the broadband USO accurately: We classified the country into several geo-types according to regional characteristics and selected sample areas to represent each geo-type. However, the geo-type methods employed in previous studies seemed unsuitable for this analysis because they were based on the geographical characteristics of the United Kingdom (Analysys Mason, 2008) or Europe (Schneir & Xiong, 2016). Thus, an appropriate approach was needed to classify the geo-types in Korea, where population density and regional characteristics differ.

Considering the characteristics of Korea, the geo-type method used to calculate fixed termination rates could be an appropriate classification approach. Fig. 2 shows the classification of geo-types in Korea for the estimation of fixed termination rates. The Korean territory was classified into nine geo-types, consisting of different combinations of connection line density and share of mountainous terrain (high, medium, and low). For each geo-type, a sample area close to the average, with minimum regional bias, was selected ($n = 20$). We accepted this approach to estimate the cost of providing universal broadband service in Korea. Considering that the fixed access technology is still commonly used for broadband USO, we chose to classify the country into nine geo-types in the same manner. Twenty sample areas representing all geo-type of Korea were similarly selected. In addition, three sample areas representing rural areas were added because households with universal fixed telephone lines identified for universal broadband services are likely to be located in rural areas.

3.3. Network architectures

In terms of a technology-neutral approach, various access technologies could be proposed as solutions for universal broadband service (Alleman et al., 2010). However, for cost-efficient deployment of broadband networks for USO, the network topology selected should reflect the characteristics of a specific broadband market. Korea already has the fifth-highest fixed-based broadband penetration among OECD countries (OECD, 2019). Therefore, providing universal service on the existing fixed broadband networks would be the most feasible and appropriate solution in the short term. Therefore, we first considered only fixed broadband access networks as the candidate for network topology to provide universal broadband service in Korea.

Among the copper-, fiber-, and cable-based fixed access networks generally employed (Schneir & Xiong, 2016), we considered only the fiber-based networks using the FTTH and FTTDP technologies, based on the number of broadband connections in Korea by technology. Since fiber-based broadband account for 81.7% of the total broadband connections in Korea, the highest share among OECD countries as of 2019 (OECD, 2019), it seems reasonable to limit the network topology employed in this study to the two fiber-based access networks. VDSL, which can reuse all the existing copper-based access networks, could also be considered from a cost reduction perspective for providing universal broadband service (Falch & Henten, 2009). However, as shown in Fig. 3, VDSL connections account for only 2.4% of all broadband connection lines in Korea as of February 2020; thus, the VDSL network is not considered in this study. The cable-based hybrid fiber coax (HFC) network is also not considered as an alternative for providing universal broadband services because the major domestic ISPs in Korea have hardly used the access technology so far.[5]

Fig. 4 shows the specific network elements of the two fiber-based network architectures employed in this study. First, for FTTH, the access network is composed of fiber cables from the central office to the customer premises. Both the Ethernet passive optical network (EPON) and the gigabit passive optical network (GPON) are generally considered in the FTTH network architecture in Korea. The optical network terminal (ONT) is also employed in the network architecture. Second, for FTTDP, while the fiber cables should be

[5] For example, as of June 2020, the biggest ISP (Korea Telecom) in Korea does not have any cable-based broadband connection lines, whereas the HFC broadband connections of the second-largest (SK Broadband) and the third-largest (LGU +) operators account for only 18.9% and 13.5%, respectively, of their total broadband connections.

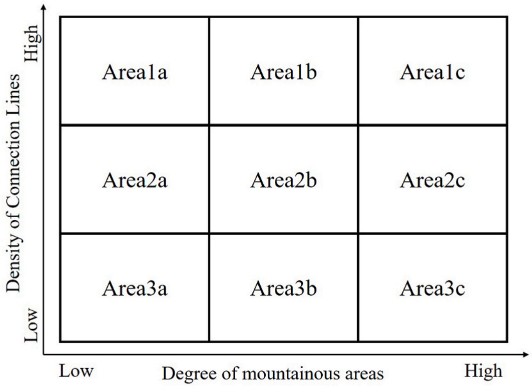

Fig. 2. Classification of the geo-types in Korea.

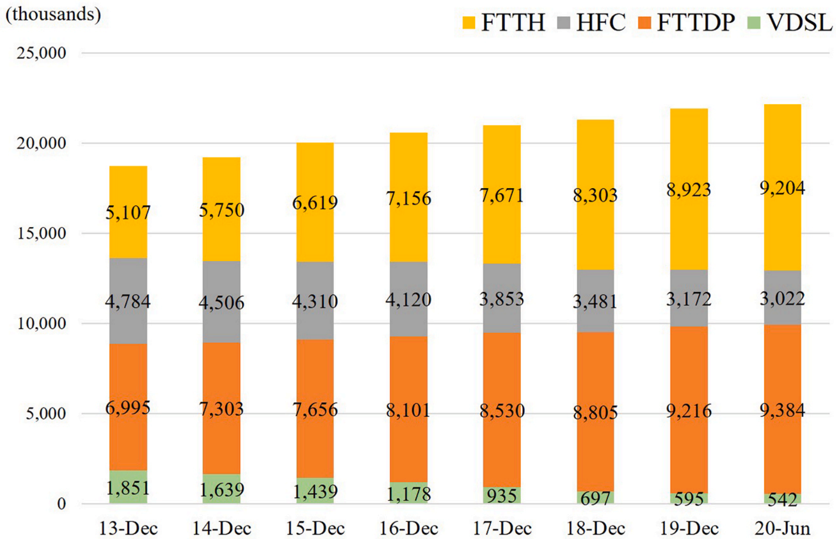

Fig. 3. Number of fixed broadband connections in Korea by access technology (FTTH = fiber-to-the-home, HFC = hybrid fiber coax, FTTDP = fiber-to-the-distribution point, VDSL = very high-bit-rate digital subscriber line).

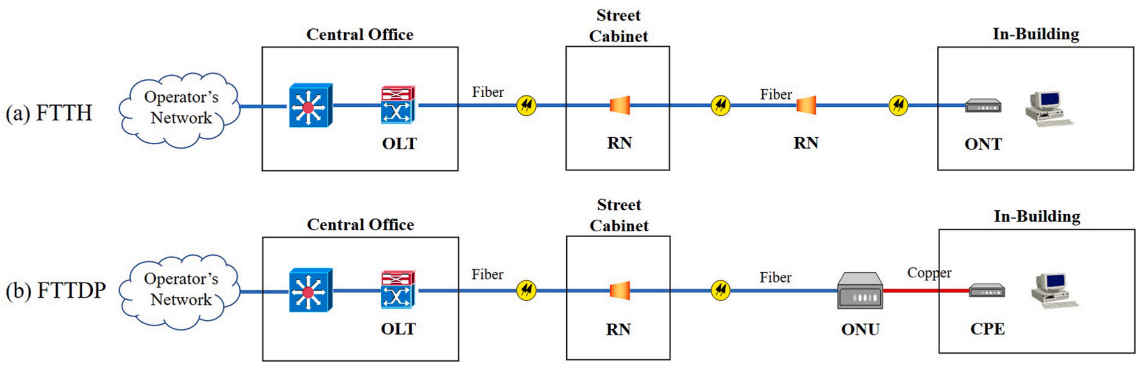

Fig. 4. Network architectures for the fiber-to-the-home (FTTH) and fiber-to-the-distribution-point (FTTDP) technologies in Korea.

deployed from the central office to the distribution point unit (DPU), the existing copper lines or unshielded twisted pair (UTP) cables could be used from the DPU to the customer premises. Both EPON and GPON are also employed for transmission over the fiber line in the FTTDP network architecture.

3.4. Cost model

This study estimated the total cost of providing universal broadband services in 23 sample areas in Korea based on the geo-types and network architectures mentioned above. First, the input data employed for this study are as follows: the number and location of entire buildings, buildings providing broadband currently, and buildings where broadband is not provided at 23 sample areas (based on data submitted by all domestic ISPs as of May 2018); geographic information system (GIS) data; and the location of the central office and the second remote node (RN) of the biggest domestic ISP at the 23 sample areas (the largest ISP is regarded as the representative and both central office and second RN locations for providing the broadband USO are assumed to be fixed). The domestic network operator, who already provides universal fixed telephone service, could be selected as a universal service provider for broadband. Thus, considering the largest ISP as a representative for broadband USO does not seem to be problematic. Besides, fixing the second RN location allows us to accurately estimate the actual cost of providing the broadband USO because the operator will use the existing access network as much as possible.

Second, the optimal and efficient access network from the central office to the terminal buildings at the 23 sample areas is redesigned under the bottom-up (BU) approach based on the input data mentioned above. The designed network is composed of two parts: a sub-network from the central office to the second RN and another sub-network from the second RN to the terminal buildings. Each sub-network was redesigned under the optimization algorithm independently.[6] The first sub-network is assumed to be deployed through the fiber cable, and the second sub-network is established through either fiber cable (FTTH) or copper cable (FTTDP) in different scenarios. As for the passive infrastructure, only the poles are assumed to be deployed in the second sub-network as a redesign initiative for cost-efficiency. The specification of the network elements employed in this study was initially obtained from the domestic ISPs and finalized to reflect the feedback from the interviews with a few professionals. The amount required to provide universal broadband service at the 23 sample areas is then calculated for each element in the redesigned access network.

Third, the total cost of the redesigned broadband access network at the 23 sample areas was estimated from the amount calculated as above and the unitary cost of each network element obtained from the domestic ISPs. From the building information used, total costs were calculated for achieving 100% broadband coverage, providing broadband to current subscribers, and offering broadband as a universal service to potential subscribers who have no access currently. Because the above-mentioned total costs include the cost of deploying the access network from the central office to the second RN, the total cost for buildings without broadband access is not applicable to the cost estimation for the universal broadband service offering. Thus, we estimated the total cost for broadband USO at the 23 sample areas by subtracting the total cost of providing broadband to current subscribers from the total cost of achieving 100% broadband coverage. The deployment cost for in-building connection lines and customer premise equipment (CPE) or subscriber modems for broadband were excluded from the estimated cost because consumers generally pay these costs for broadband service in Korea. The installation cost for the core network is also excluded under the assumption that additional core network are not required for providing universal broadband service in Korea. Besides, this study did not consider indirect costs, operating expenses, and cost of capital, which are part of annualized costs, because we focused on the total deployment cost of the broadband access network for USO in Korea.

Finally, we estimated the total cost for the introduction of the broadband USO in Korea based on the total cost for the 23 sample areas. Considering that these sample areas are representative of the nine geo-types across the country, the average cost per building at each geo-type could be calculated using the average cost per building of each sample area. The cost per building was estimated for each sample area by dividing the total additional cost of providing universal broadband service by the number of buildings where broadband is currently not provided. Therefore, the total cost of providing universal broadband service nationwide was obtained by multiplying the average cost per building for each geo-type by the number of buildings at the geo-type where broadband is not provided.

4. Results and policy implications

4.1. Results

Table 2 shows the findings related to the network deployment cost per building by geo-type, access technology, and broadband speed employed in this study. First, the cost per building was higher for the geo-type Area 3 than for Area 1 and Area 2. For example, the average cost per building for the broadband offering at 100 Mbps with FTTH technology in Area 3 is 2.26 times as high as in Area 1. Since the geo-type Area 3 includes most of the rural areas in Korea, this result implies that the cost of providing universal broadband service in rural areas is relatively higher than in urban areas, which is consistent with previous studies (Schneir & Xiong, 2016; Oughton, 2016). The high cost per building in rural areas also means that the length of access network between the second RN to the terminal building deployed for the broadband USO is relatively long due to the current inadequate broadband coverage in rural areas.

Second, there is no single cost-effective access technology for broadband USO across the country. Instead, depending on the geo-type, either FTTH or FTTDP was selected case by case as the cost-effective access technology for the broadband USO. For example, Table 2 shows that FTTH is more cost-effective in urban areas (Area 1) and FTTDP, in rural areas (Area 3). This implies that it is not

[6] Although the access network from the central office to the second RN is redesigned under the BU approach without considering the current network architecture of the domestic ISP, the redesigned network does not affect the estimation of the total cost of providing universal broadband service in Korea.

Table 2
Investment per building for the broadband USO in Korea (Korean Won).

		FTTH			FTTDP			Least-Cost Technology		
		20 Mbps	50 Mbps	100 Mbps	20 Mbps	50 Mbps	100 Mbps	20 Mbps	50 Mbps	100 Mbps
Area 1 (High density)	Area1a	506,008	506,008	505,777	648,989	648,989	648,643	406,469	406,469	406,311
	Area1b	459,861	460,322	460,783	607,522	607,984	608,447	370,459	370,920	371,381
	Area1c	704,049	704,049	704,049	1,027,851	1,027,851	1,027,851	648,127	648,127	648,127
	Total	554,504	554,628	554,637	754,367	754,492	754,431	471,111	471,235	471,268
Area 2 (Medium-density)	Area2a	682,000	682,000	671,828	839,898	839,898	832,131	576,591	576,591	568,868
	Area2b	935,069	935,285	935,502	1,314,724	1,315,796	1,316,867	875,078	875,233	875,387
	Area2c	1,463,692	1,456,476	1,460,991	1,723,984	1,718,251	1,726,334	1,334,414	1,328,084	1,332,449
	Total	1,097,625	1,095,724	1,091,494	1,355,206	1,354,195	1,351,759	992,272	990,673	987,118
Area 3 (Low density)	Area3a	1,389,436	1,313,838	1,313,265	1,406,771	1,352,257	1,377,913	1,167,505	1,107,657	1,111,552
	Area3b	1,166,767	1,156,358	1,150,153	1,127,611	1,120,640	1,120,176	936,424	928,545	924,415
	Area3c	1,289,857	1,277,266	1,277,106	1,183,151	1,173,408	1,176,088	1,021,623	1,011,726	1,011,718
	Total	1,274,304	1,255,513	1,254,030	1,196,323	1,183,202	1,188,037	1,019,552	1,005,141	1,004,766

Note: FTTH = fiber to the home; FTTDP = fiber to the distribution point.

necessary to establish additional high-speed Internet access networks with FTTDP in well-deployed urban areas. However, FTTDP is more suitable for broadband access networks in rural areas, where groups of buildings can be easily identified for broadband provision as a universal service. Moreover, the cost per building for the least-cost technology was almost always lower than in other cases, meaning that the technology-neutral approach could contribute to cost-effective deployment of broadband for USO. Table 2 also shows that, in rural areas (Area 3), the average cost per building for 100 Mbps with the least-cost technology is 80.1% of the FTTH and 84.6% of the FTTDP deployment costs, indicating the necessity of a technology-neutral approach for providing the universal broadband service in rural areas.

Third, despite the positive relationship between broadband speed and cost per building, the cost per building did not significantly differ between 50 Mbps and 100 Mbps. This means that the network elements used to establish the fiber-based broadband access network for 50 Mbps and 100 Mbps were no different. Therefore, domestic ISPs could quickly increase broadband speed from 50 to 100 Mbps without additional deployment of network elements under the fiber-based network. The average cost per building for providing broadband at 100 Mbps in rural areas (Area 3) ranges from 0.92 to 1.39 million Korean Won (see Table 2). This seems acceptable because the cost is recoverable within 46 months at most from the monthly broadband fee (30,000 Korean Won per month).

The total cost necessary for providing universal broadband services at the national level was estimated by multiplying the average cost per building by the number of buildings to be provided with broadband as a universal service by geo-type. Table 3 and Fig. 5 show the total deployment costs of the broadband USO for the three access technologies and the three broadband speed levels analyzed in the study. If all the geo-types were to be covered with FTTH, the total cost would range from 1.08 trillion (at 20 Mbps) to 1.10 trillion (at 100 Mbps) Korean Won. With FTTDP, however, it would range from 1.01 trillion (at 20 Mbps) to 1.04 trillion (at 100 Mbps) Korean Won. With the least-cost technology, the total cost would range from about 0.86 trillion (at 20 Mbps) to 0.88 trillion (at 100 Mbps) Korean Won. Fig. 5 also shows that the cost of providing broadband USO is largely attributable to deploying the service in rural areas (Area 3). Regardless of the speed and access technology, providing broadband as a universal service in urban (Area 1) and sub-urban (Area 2) areas cost only about 1% of the total amount spent for broadband USO deployment in Korea.

4.2. Policy implications

The results analyzed in the previous section highlight a series of issues that need to be considered by policymakers. First, the results of this study support the introduction of universal broadband service in Korea in terms of the estimated costs. Estimating the reasonable cost of providing universal broadband service nationwide through the proposed model is a meaningful exercise to evaluate the government's broadband USO decision. According to the estimation results, the average cost per building for a 100-Mbps broadband network could be recovered within 4 years at most from the monthly broadband fee. Furthermore, the total cost of providing broadband USO at 100 Mbps through the least-cost technology would be 0.88 trillion Korean Won, which is a relatively low amount compared with previous estimations (Bogojevic, 2012; Stocker & Whalley, 2019). Besides, as Stocker and Whalley (2019) suggested, since the number of eligible buildings receiving broadband speed of less than 100 Mbps has declined considerably, the total cost of providing the broadband USO in Korea could be still lower than estimated in this study.

Second, this study shows some evidence that justify the Korean government's decision setting the broadband speed for the USO at

Table 3
Total cost for the universal broadband service offering in Korea (billion Korean Won).

	FTTH	FTTDP	Least-Cost Technology
20 Mbps	1080.7	1014.6	864.6
50 Mbps	1087.0	1024.4	870.2
100 Mbps	1096.6	1038.9	878.6

Note: FTTH = fiber to the home; FTTDP = fiber to the distribution point.

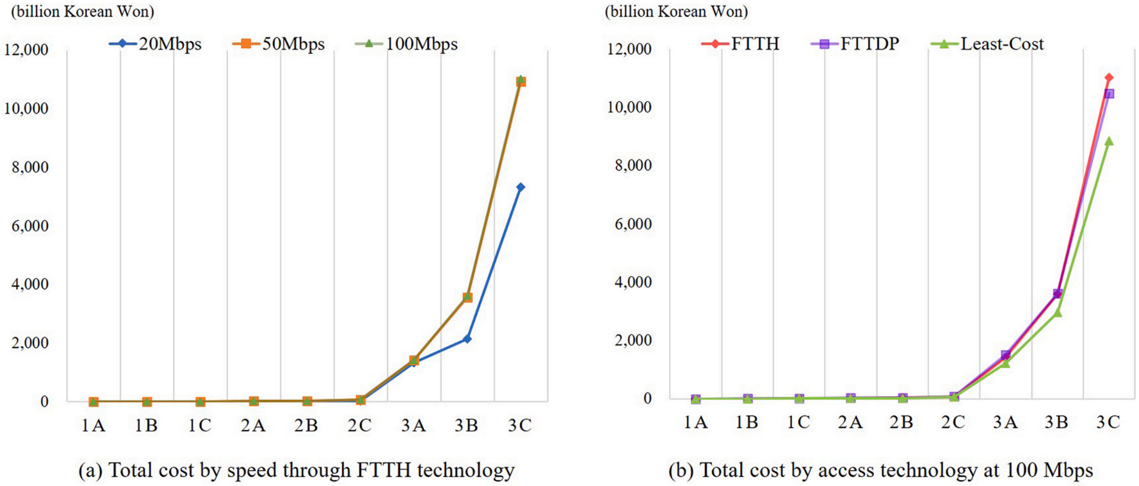

Fig. 5. Total cost for the universal broadband service offering by geo-type for different scenarios (FTTH = fiber to the home; FTTDP = fiber to the distribution point).

100 Mbps, at least from a cost perspective. Although providing broadband at 50 Mbps with the existing VDSL technology produces some cost savings, VDSL connections account for only 2.4% of all broadband connection lines in Korea. Therefore, we agree that the cost-saving is lower than the economic benefits from providing the service at 100 Mbps. Moreover, to facilitate migration from copper-to fiber-based broadband access networks, a speed obligation higher than 50 Mbps may need to be imposed, at least in the developed countries. Although there are many considerations that decide the speed required by USO (Stocker & Whalley, 2019), the government can easily increase the broadband USO speed in the future as the access network would have migrated to fiber-based network architectures. This study finds that the average deployment cost of broadband USO per building does not significantly differ between 50 and 100 Mbps. This demonstrates that universal broadband service of at least 50 Mbps through the optical-based access technology might be acceptable in the developed countries. To provide more robust evidence to policymakers, researchers might also analyze whether the cost-saving from providing broadband USO through the copper-based VDSL technology is less than the economic benefits of providing the service at high speed.

Lastly, more cost-effective alternative access technologies might be considered, with a technology-neutral approach, to provide universal broadband services. Because the cost of deploying broadband via fixed access networks increases sharply with the length from the existing street cabinet to the terminal building, wireless access technologies such as FWA can be cost-effective alternatives, consistent with previous studies (Alleman et al., 2010; Stocker & Whalley, 2019). This study also addressed the relationship between the length of the access network deployed for the broadband USO and the total cost. According to the results, buildings more than 500 m away from the existing street cabinet account for only about 15% of all buildings eligible for broadband as a universal service (see Table 4). However, the total cost for all buildings amounts to, at most, 45% of the entire cost for the broadband USO in Korea. This means that the cost burden for providing universal broadband service via a fixed access network would be high enough to restrict the diffusion of the universal service in rural areas. Therefore, although the total cost of providing fiber-based universal broadband services in Korea is reasonably acceptable, the government could consider including wireless access technology as a technological alternative to reduce the costs of the USO policy. However, careful and comprehensive evaluation is necessary to determine whether wireless access technologies could be accepted to provide universal services by considering other perspectives, in addition to the cost for deploying the network. For example, as wireless broadband services through FWA have not been released in Korea, service operators might encounter difficulties in providing universal services via FWA, such as supplying new terminals and introducing new unlimited data usage plans at a similar fee level as that of other universal broadband service providers via fixed networks. The speed obligation of 100 Mbps as USO could also be another constraint because this speed obligation is still challenging to meet constantly via

Table 4
Total cost based on the length of the access network (billion Korean Won).

Length of access network deployed	Percentage of buildings	Total cost for the broadband USO at 100 Mbps		
		FTTH	FTTDP	Least-cost technology
0–80 m	47.8%	196.4	161.4	118.6
80–200 m	25.8%	206.5	203.9	161.1
200–300 m	6.1%	100.2	113.7	90.6
300–400 m	3.3%	73.9	81.6	67.1
400–500 m	2.1%	54.1	58.3	49.5
500 m∼	14.9%	472.5	428.7	397.9

Note: FTTH = fiber to the home; FTTDP = fiber to the distribution point.

cellular-based mobile networks.

5. Conclusion

The introduction of universal broadband service at 100 Mbps in Korea in 2020 is an appropriate case to evaluate the need of broadband USO. Although both broadband itself and its speed are becoming increasingly important in all spheres of society, the high cost of providing high-speed broadband as a universal service raises a question: Was the USO introduction really necessary? An appropriate estimation of the network deployment cost for the broadband USO can not only support government decision making but also help evaluate if the government's decisions were appropriate from a cost perspective. This study proposes a cost estimation model for the universal broadband service in Korea and assesses whether the USO introduction was appropriate. In particular, since the proposed model is based on the bottom-up (BU) approach, which establishes an efficient network using the latest technologies, the model could provide an accurate and reliable cost estimation for the nationwide universal broadband service in Korea.

The main findings of this study are as follows: First, the total cost of providing broadband USO at 100 Mbps through the least-cost technology was at 0.88 trillion Korean Won. This is a relatively small amount compared with previous assessments (Bogojevic, 2012; Stocker & Whalley, 2019) and could be recovered within a reasonable period from the monthly broadband fee that subscribers pay. Therefore, this result supports the introduction of universal broadband service in Korea. Second, the average cost of broadband USO per building did not significantly differ between 50 and 100 Mbps, implying that the Korean government's decision setting the broadband speed for USO at 100 Mbps was reasonable enough, at least from a cost perspective. These results suggest that developed countries with relatively high broadband penetration, in particular, could provide universal broadband services at a minimum speed of 50 Mbps through fiber-based technologies. Lastly, although the total cost of providing fiber-based universal broadband services could be reasonably acceptable in Korea, the government could adopt a technology-neutral approach and include wireless access technology as a technological alternative to reduce the costs of the USO policy.

Despite some meaningful implications, this study also has some limitations. First, since the universal broadband service has just started in 2020, the relationship between the USO policy and broadband development could not be addressed. Further research is necessary to study the issue quantitatively. Besides, this study focused on estimating the total cost of providing the USO nationwide, and thus did not calculate the annualized cost, including capital expenditures (CAPEX) and operating expenditures (OPEX). Further research estimating the annualized cost of the broadband USO operations could contribute to the USO policy implementation in terms of funding methods.

Declaration of competing interest

None.

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