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RURAL AND REMOTE BROADBAND DEVELOPMENT IN THAILAND: ENABLED BY LAST-MILE INFRASTRUCTURES AND SERVICES

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ABSTRACT

Currently digital economy is one of the main national policy of the Thai government to fundamentally and extensively reform Thailand in all social and economic perspectives where the ICTs and digital technologies are comprehensively leveraged to drive the country forward. However, a big digital gap exists between urban and rural/remote areas. This paper illustrates new tailored last-mile technologies, which are suitable to the areas. The main goals of this development and implementation are to 1) provide high-speed broadband internet services and mobile services in the areas, 2) extend infrastructures and services to the areas so that remote people will be provided equal access to digital technology and information, 3) create the so-called digital economy and society in the areas, and 4) leverage digital technologies and services for the areas. The paper focuses on the area issues and requirements related to broadband accesses and presents an implementation solution which is efficient and economical for the areas. It also discusses related implications.

1. INTRODUCTION

Technologies and Innovations are transforming on how to live, to communicate and to do businesses. The growth of information and communications technologies (ICTs) including social network, the Internet of Things (IoT) (Vijayasaro and Niveathasaro, 2019), cloud computing, mobile applications, and big data computations have driven a key role in people behaviors and how they develop their businesses. Therefore, governments worldwide especially developing countries as Thailand are assessing and implementing a digital strategy and policy. It is proposed to support and enhance their public services and administrations with the power of ICTs for citizens to employ digital services more availably, effectively and efficiently. Once this strategy and policy is fully implemented, a stage will be set for more integrated e-Government and ICT applications such as e-Commerce, e-Education, e-Health,

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e-Environment, etc. Besides, ICTs are recognized as an effective tool to enhance economics and financial opportunities for the people in the areas by encouraging them to do businesses with sufficient knowledge to take advantage of these technologies (LaRose et al., 2006). With the economic aspects and social impact of broadband, there have been growing concerns of the role and potential effect of broadband in rural/remote areas (Preston, 2001). However, rural/remote areas in developing countries are characterized as the recognized ICT-Deficit such as inadequate infrastructure issues, non-availability of reliable power supply, non-affordability of Broadband access (Foros & Kind, 2003), lack of awareness and digital capability, and lack of implementable operator justification (GAO, 2006; Schmandt et al., 1991; Venkatachalam & McDowell, 2002). As a result, there will be lack of broadband penetration in these types of areas, thus creating a big digital divide within countries in terms of accesses to and usages of ICTs between urban and rural/remote areas, where broadband adoption in terms of income, education, and age can be analyzed to obtain insightful information on what is the limitation in the areas and on how to implement an innovation to close this constraint (Rogers, 2003).

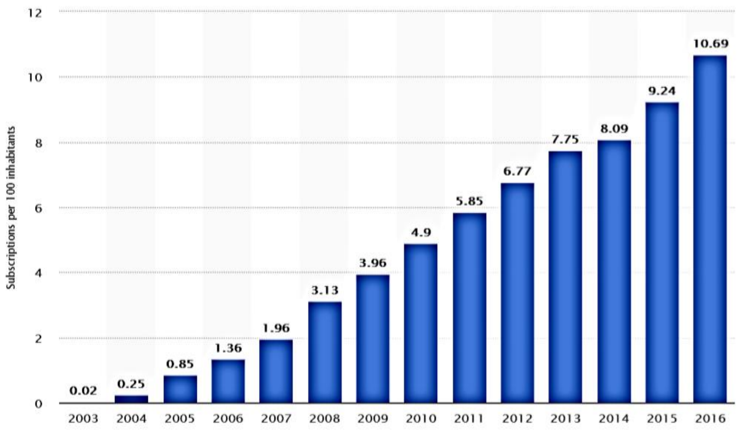

Figure 1: Number of fixed broadband subscriptions per 100 inhabitants in Thailand (World Telecommunication/ICT Development Report and database, 2017).

Digital economy currently is the main national policy of the Thai government, called "Thailand 4.0", to fundamentally and extensively reform Thailand in all social and economic perspectives where the ICTs and digital technologies are comprehensively leveraged to drive the country forward. One of the main goals is to reduce the inequality by allowing people to equal access to the ICTs and digital technology so that their income, education, and healthcare can be more prolific. This will reduce the digital divide gap (Grubesic, 2003; Grubesic & Murray, 2002, 2004) and ensure that millions of rural/remote people can access information and services thru suitable last-mile communication technologies and then exploit the maximized benefits of advanced digital technology as noted in the plan, "All Thais will have access to broadband internet, as a basic utility. Quality of life will be improved through inclusive access to information and essential public services". While the accelerating growth of technologies continues, with this implementation rural/remote people can gain access to these services and be able to drive their own innovation development and education. By developing of last-mile technologies in these underserved areas, the government can close the digital divide and create economic impacts on several aspects where jobs and acts are created as the result to productivity gains and creation of new businesses (LaRose et al., 2006). Many studies showed that the impact of broadband penetration contributes aggregately on the Gross Domestic Product (GDP) growth with a larger and more skilled labor force and increased working capability (Crandall et al., 2007; Katz et al., 2010). As this effect can be seen more significant and higher in developing countries than developed country (Crandall et al., 2007; Katz et al., 2010; Czernich et al., 2009; Ford & Koutsky, 2005). Therefore, the broadband penetration is a key factor, which is often used as a benchmark as a reference of national economy and society conditions. Figure 1 shows Thailand's broadband penetration from 2003 to 2016. In addition, Figure 2 shows that today Broadband is considered as a central element of a new ecosystem. People can exploit high-speed broadband internet accesses and services to organize their local businesses and enhance the productivity

According to the Thailand Digital economy plan, two of the main assigned Thai government agencies, Office of the National Broadcasting and Telecommunications Commission (NBTC) and Ministry of Digital Economy and Society (MDES), have set the national targets for last-mile extension and implementation by dividing Thailand into four economic zones as shown in Figure 3. In this paper, we will use the definition in Figure 3 as the reference on how rural and remote areas are determined.

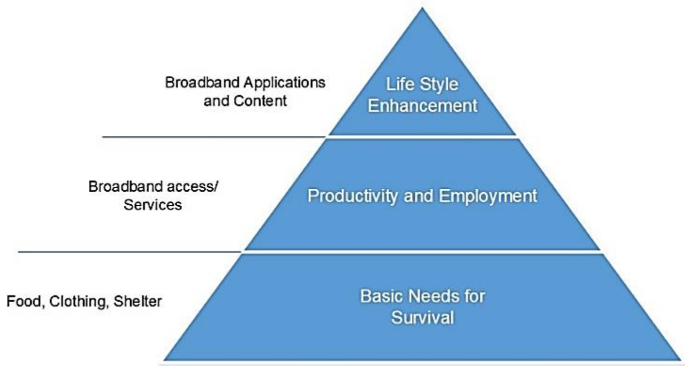

Figure 2: Analogy with MASLOW's Pyramid: Role of Broadband for basic Human.

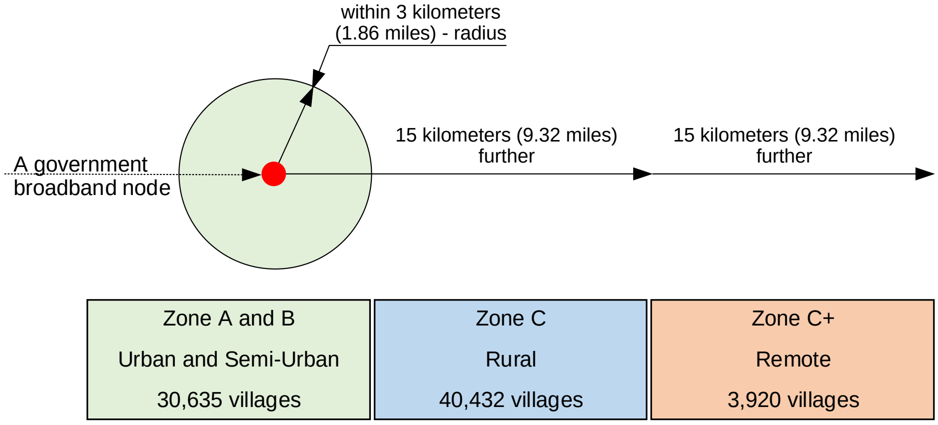

Figure 3: Thailand's four economic zones.

In this paper, we focus on the case study of providing last-mile technologies for 15,732 rural villages (Zone C) and 3,920 remote villages (Zone C+) implemented by NBTC. This paper illustrates new tailored last-mile technologies which are suitable to these types of areas. The technologies are aimed to be the base on which to construct a regional system for distribution of broadband accesses at 15,732 rural villages and broadband/mobile accesses at 3,920 remote sites locating around the country as shown in Figure 4. It is noted that MDES is responsible for the broadband implementation of remaining rural villages (24,700 rural villages).

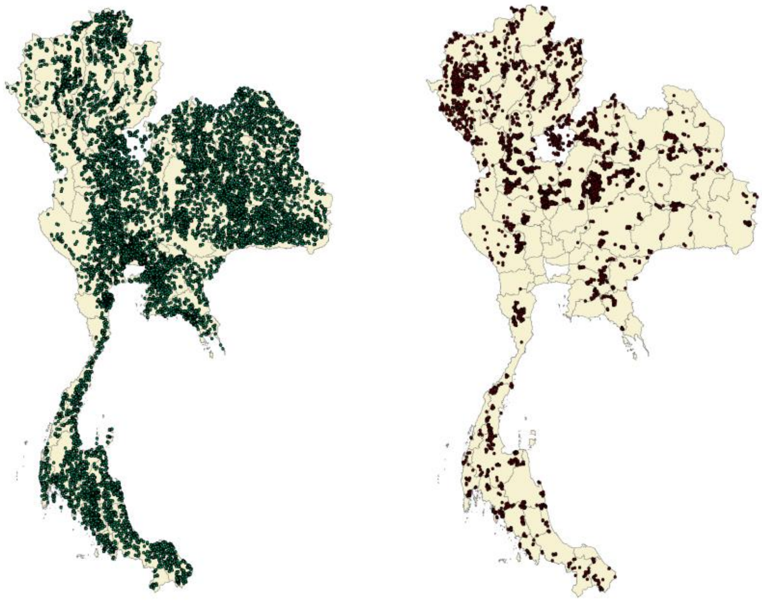

Figure 4: targeted rural (Zone C) and remote (Zone C+) villages around the country.

2. CASE STUDY WITH CHALLENGES TO SUSTAINABILITY IN REMOTE AREA

The case study presented in this paper is the last-mile implementation for the 3,920 remote villages in Thailand by NBTC. The objectives of this development and implementation are to 1) provide high-speed broadband internet services and mobile services in the areas, 2) extend infrastructures and services to the areas so that remote people will be provided equal access to digital technology and information, 3) create the so-called digital economy and society in the areas, and 4) leverage digital technologies and services for the areas. The 3,920 implemented remote villages are located in all remote areas in Thailand as shown in Figure 4. Most of them are in the north of Thailand, a mountainous area with parallel high mountains with steep river valleys and high-hill areas that surround the central plain. While the 15,732 rural villages are more distributed nationwide and most of them are easier to access compared to the remote area. However, there are approximately 20-30% of the areas have the same constraints as the remote.

Table 1: Descriptive Information of the rural and remote villages (Archived from our survey information).

Area: Zone C	Targeted villages	Approximate population	Average population per village	no. of Teachers	no. of Students
North	4,140	2,460,432	594	19,716	241,340
South	2,052	1,713,722	835	14,288	182,610
Central and East	3,367	2,202,084	654	18,489	239,028
North-East	6,173	3,823,091	619	29,559	392,074
Total	**15,732**	**10,199,329**	**648**	**82,052**	**1,055,052**
Area: Zone C+	**Targeted villages**	**Approximate population**	**Average population per village**	**no. of Teachers**	**no. of Students**
North	2,027	868,041	428	11,351	148,760
South	459	239,526	522	2,757	33,919
Central and East	349	182,122	522	1,755	27,237
North-East	1,085	534,209	492	5,120	66,473
Total	**3,920**	**1,823,898**	**465**	**20,983**	**276,389**

The last-mile technology is designed to meet the requirements and constraints of the areas so that it can provide both high-speed broadband internet services and mobile services efficiently and economically in the areas. Therefore, there are vital challenge to be considered in determining an implementable and practicable technology solution for this remote area scenario. Some various challenges for the sustainability for remote broadband services are discussed as follows:

2.1 FUNDAMENTAL CONSTRAINTS

2.1.1 LOCATION ISSUE

For the remote villages, most of the villages are on the mountains or surrounded by the mountains. From Table 1, there are approximately the total of 1,823,898 populations with the average of 465 people per village. Household locations are scattered and unevenly. Some of them can be found as a group of average 20-30 Households. While for the rural area, from Table 1, there are approximately the total of 10,199,329 populations with the average of 648 people per village. In summary, the remote villages are the areas with very low density, while the rural villages are the areas with sparse residential density as shown in Figures 5 and 6, respectively. In the last-mile implementation for both types of areas, descriptive rural/remote locations can make relatively higher total cost of ownership in terms of transportation and maintenance including labor and construction cost even through prices for hardware and software are dropping.

Figure 5: A targeted remote village in the north of Thailand. (Courtesy of Google Map)

2.1.2 AFFORDABILITY

Affordability of broadband accesses by end-users is another crucial factor which directly impacts the growth of broadband services and also is the key restriction for remote households to go online (Foros & Kind, 2003). For private network providers, the return of investment (ROI) from this service for remote households is very low (about 3-6% of per capita income). In these remote areas, household income is 5,659 Thai baht a month on average (about 161USD) with the maximum and minimum of 37,567 and 657 Thai baht a month (1,073USD and 18USD) respectively (CDD; GSIC). Household income is greater by merely 5-10% in the rural areas so that there is no much difference among the areas

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in terms of affordability. In the result, the price of a broadband access plays a vital role in driving the success of broadband penetration (Bell et al., 2004; DeLong et al., 2002). Also, it is a vital barrier for remote people to gain access to the Internet in developing countries such as Thailand. Even though broadband accesses are more affordable as prices have been dropping over the last few years, it remains unaffordable for the remote people with their limited incomes.

Figure 6: A targeted rural village in the north of Thailand. (Courtesy of Google Map).

2.1.3 LACK OF AWARENESS AND DIGITAL CAPABILITY

There are limited knowledge and resources for the remote population (NTIA, 2009). The implementation of broadband and mobile services alone is not adequate to make rural/remote people be able to fully utilize the benefits of the digital services. People in these areas quite lack of the required skills on how to take advantages of these technologies. They may not realize benefits with proper uses. Building awareness of the digital capability and benefits thru broadband and mobile accesses is an important initial step to create mass demands. Necessary skills are needed for remote people to successfully use Broadband. Therefore, a learning society is needed to create to provide fundamental information to them and new ways of learning, thus leading to a productivity gain by facilitating the adoption of more efficient business processes. The impacts of the technology on productivity, employment and innovation are shown in Crandall et al. (2007), Crandall et al., (2003).

2.1.4 NON-AVAILABILITY OF RELIABLE POWER SUPPLY

The reliable grid power supply in Thailand has not been developed as fast as the spread of telecommunication and broadband infrastructure, especially in the remote areas. About 5-10% of the 3,920 villages do not have any electricity or do have insufficient power source. In this case, optional power supply such as solar power is considered to be a self-sustainable and capable power to broadband and mobile equipment. Nonetheless, according to our survey information, there is only 1-2% of the rural area with such power constraints.

2.2 TECHNICAL CONSTRAINTS

2.2.1 INFRASTRUCTURE ISSUES

As seen, the growth of Broadband penetration in the remote areas is one of the challenges since there is insufficient infrastructure or backhaul. Implementing a broadband or mobile infrastructure in the remote area needs more specialists and higher cost of ownership for which private network operators find it unlikely to justify the investment over that long-distance network with low population density (Hollifield & Donnermeyer, 2003). Therefore, last-mile implementation should be reliable, affordable, scalable and financial viability. Various technologies may be suitable for last-mile broadband implementation as the backhaul in the remote areas such as Fiber (Passive Optical network: GPON), Satellite or Microwave. Each of these technologies has its benefits and drawbacks in terms of affordability, performance and total cost of ownership (TCO). As a result, no single technology solution can fit all remote area scenarios. About 60% of the 3,920 villages do not have any existing internet access (currently no available network connectivity). However, according to our survey information, there are no such obstacle for most of the rural area where internet accesses thru public and/or private network providers already exist.

2.2.2 NEED FOR IMPLEMENTABLE DIGITAL SERVICES

No feasible and prolific commercial business model in the rural/remote areas is the main reason why there is the lack of Broadband penetration. People in the areas do not have sufficient knowledge to take advantage of these technologies. The traditional business model does not sustain in the rural/remote areas where population density is very low. It is necessary to find effective ways to empower and enable a sustainable model across all stakeholders in the areas (CEU, 2006).

Table 2: Considered factors in the optimization problem.

Factors	Description
Users	Stakeholders, Gender, Age, Internet experience, Self-efficacy, Education
Physical	Location, geographic limitation, Accessibility, Landmarks (School, Temple, Hospital, etc.)
Social	Usages, Activities, federal, state, and local agencies
Facility	Electricity, Water, Energy
Infrastructure and Communication	Current Broadband and mobile service
Cost	Implementation and Maintenance

3. TECHNOLOGY ALTERNATIVES AND IMPLEMENTATION FOR ACCESS, BACKHAUL, AND DEVICES

3.1 BROADBAND IMPLEMENTATION AND SERVICES

With the mentioned technical constraints in the previous section, for broadband implementation, there are two main considerations needed to find solutions for the remote area. First, are the infrastructure issues (see Section 2.2.1). Secondly, the lack of awareness and digital capability (see Sections 2.1.3 and 2.2.2) is concerned. Since in the rural area, there already has been existing network infrastructure and access, the second solution is the only aware. In Kanungo et al., 2002, the use of geographical distribution is derived into a development plan with clustering techniques such as K-means Clustering or Self-Organizing Map (Kanungo et al., 2002; Bação et al., 2005). With these clustering approaches, we are able to divide the remote villages in several clusters in terms of infrastructure issues and the lack of knowledge. In order to achieve economic constraint, an optimal location in a cluster is determined by solving an optimization problem:

$$\text{Maximize utility functions } U = \text{Sum}\,(w*f(x)),$$
$$\text{Subject to } g(x) \leq 0,$$
$$h(x) = 0, \qquad (1),$$

where x = considered factors shown in Table 2, g(x) is inequality constraints and h(x) is equality constraints.

As a result, the broadband implementation solution provides two layers of services: 1) network infrastructure (backhaul) and 2) Digital services and applications thru Wi-Fi technology and Learning center. For the remote villages, first, if applicable, the fiber (Passive Optical network: GPON) technology is exploited with an optical line termination (OLT) is installed at the optimal location in a cluster as shown in Figures 7 and 8. There are the total of 881 OLTs to support 4,760 services (Customer-premises equipment (CPE)/Optical Network Unit (ONU)) in the 1,909 remote villages (previously no any existing internet infrastructure). This technology can support high-speed internet accesses with more than 30/10 Mbps data rate (Download/Upload) per a service point (ONU). In case of geographic limitation over too long distance for the fiber technology in terms of technical and cost limitations, the broadband satellite capacity can be exploited to provide an internet backhaul for broadband services with more than 30/5 Mbps data rate (Download/Upload) per a service point (CPE) at remote sites.

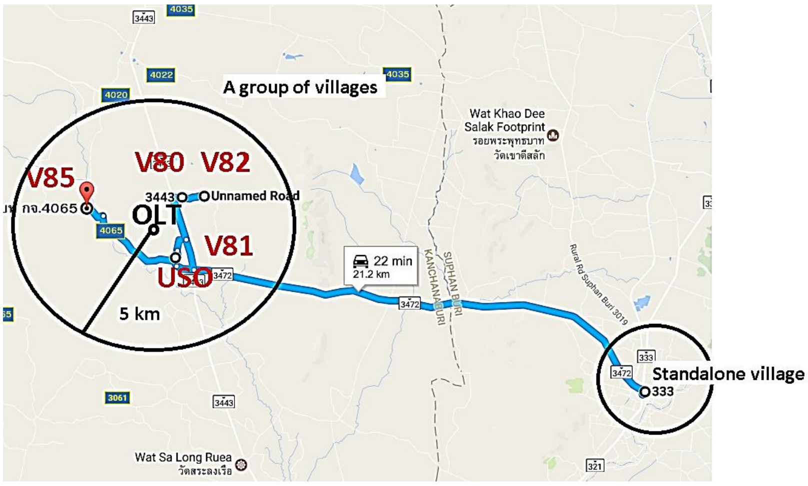


Figure 7: A remote targeted village in the north of Thailand. (Courtesy of Google Map)

For the remote villages, secondly, there are the total of 3,149 fixed wireless broadband services (Free Wi-Fi services) installed at schools and/or public locations which is calculated to be optimal locations to provide services in their clusters. They support more 100 concurrent users with IEEE 802.11a/b/g/n/ac and IEEE 802.11e (Wireless Multimedia) and the data rate of 1300 Mbps at 5 GHz and 450 Mbps at 2.4 GHz. The fixed wireless broadband services can provide high-speed internet connectivity with a low cost of implementation and maintenance.

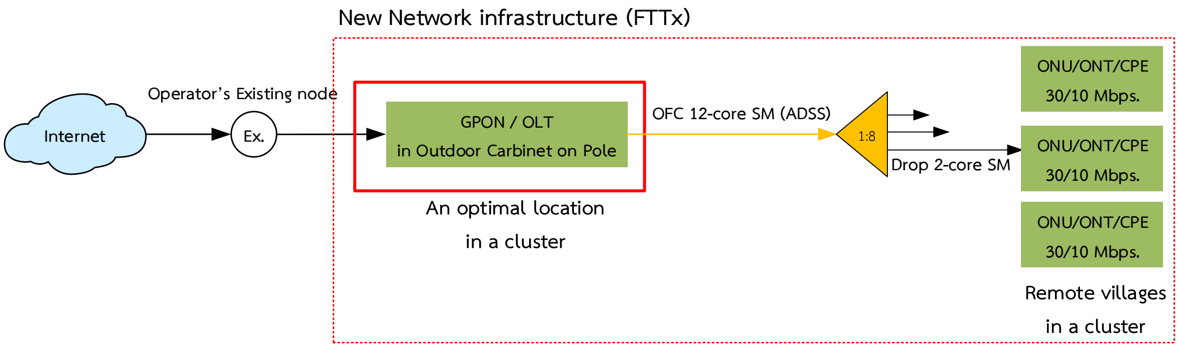


Figure 8: GPON network infrastructure (backhaul).

Besides to the fixed wireless broadband services (Free Wi-Fi services), 763 Learning centers at schools are calculated to be optimal locations to provide services in their clusters. A Learning center not only provide high-speed internet access but also provide enough learning tools and resources, i.e., computers, learning course, etc. Both fixed wireless technology and Learning center services will reduce limited end-user awareness and insufficient digital knowledge among most of the area of the remote population. Figure 9 shows the total solution for the Broadband implementation and services in the remote area.

For the rural villages, there are only digital services implemented, i.e., fixed wireless broadband services (Free Wi-Fi services) and Learning centers at schools in order to overcome the fundamental constraints (Affordability and Lack of Awareness and Digital capability and technical constraint (Need for implementable digital services) discussed in Section 2. From (1), the optimal calculated result will be the locations of Learning centers at schools in the areas. Table 3 shows the summary of broadband implementation and services in the rural and remote areas.

Table 3: Broadband implementation and services in the rural and remote areas.

Infrastructure/Digital services	Rural area (Zone C)	Remote area (Zone C+)
GPON (Figure 10)	Existing network	Passive Optical network with 881 OLTs installed
Free Wi-Fi services (Figure 11)	15,723	3,149
Learning centers at schools (Building) (Figure 12)	228	763
Learning centers at schools (Room) (Figure 13)	1,623	-
Free Wi-Fi services at schools (Figure 14)	3,170	1,210
Free Wi-Fi services at local hospitals (Figure 14)	91	107

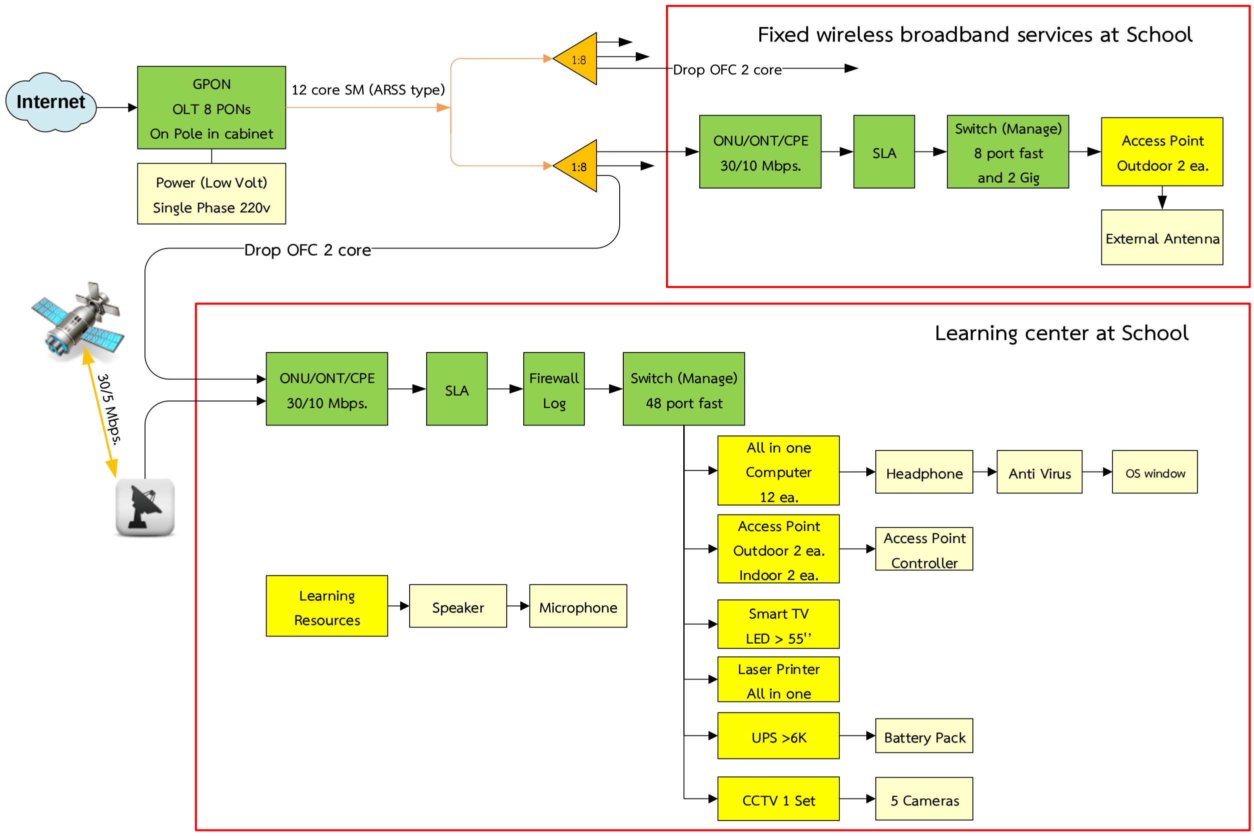


Figure 9: Total solution for the Broadband implementation and services.

Figure 10: Infrastructure: GPON

Figure 11: Digital services: Free Wi-Fi services

Figure 12: Digital services: Learning centers at schools (Building)

Figure 13: Digital services: Learning centers at schools (Room)

Figure 14: Digital services: Free Wi-Fi services at schools and local hospitals

3.2 MOBILE IMPLEMENTATION AND SERVICES

Currently, 4G is a main technology for mobile phone in Thailand while 3G and 2G service still exists. According to a report, the mobile penetration in Thailand is more than 100% and is still increasing. This may mean that the mobile networks may already penetrate the remote areas. In fact, however, as mentioned most of the target areas are in mountainous regions, no service operator can cover all of the area. Macrocell technologies (3G and 4G) carry most of the traffic in today's mobile network but with the geographic constraint, the technologies are not suitable to employ in these types of areas. In order to meet the geographic requirements, we survey all of the 3,920 villages by measuring received signal strength (2G/3G/4G) of all service operators at particular spots in each village area as show in Figure 15. If no single service operator can provide more than -85 dBm of received signal in the spot (The basic of Cellular signal strength), a mobile site in the village will be recommended to implement.

In a result, we found that there are the total of 4,916 particular spots in the areas of 1,890 remote villages which have received signals less than the criteria as shown in Table 4. Nonetheless, there is at least one mobile provider in the rural area so that there is no necessary to implement any mobile implementation and services in the area.

We have to implement different technologies for backhaul corresponding to the location requirements in each area. For example, in order to provide mobile service coverage in the remote areas, where household locations are scattered and unevenly on the mountains or surrounded by the mountains, broadband satellite solution is an optional and suitable solution for geographic limitation over too long distance for the fiber technology in terms of technical and cost limitations, the broadband satellite capacity can be exploited to provide an internet backhaul for broadband services with more than 30/5 Mbps data rate (Download/Upload) per a service point (CPE) at remote sites. In the remote areas, the economics of the deployment of mobile infrastructure for mass access are limited. Deploying large scale of mobile services has involved high investment compared to low density of population with very small subscribed power. An appropriate selection of mobile technology options are main technical factors for defining a deployed architecture for the remote areas and meet all of their constraints. There are a number of different technologies and terms which have been used across parts of the industry (Thota, Nag, Divyasukhananda, Goswami, Aravindakshan, Rodriguez, Mukherjee, & Nandi, 2013).

Figure 15: particular spots in each village area for measuring received mobile signal strength (Courtesy of Google Map).

Table 4: Descriptive Information of particular spots in the areas of 1,890 remote villages (Zone C+).

Area: Zone C+	Total villages	Total implemented particular spots	Implemented villages
North	2,027	2,819	988
Central and South	808	912	379
North-East	1,085	1,185	523
Total	**3,920**	**4,916**	**1,890**

With the consideration perspectives: 1) about 100 meter-radius coverage to service a group of average 20-30 Households in the area and quick deployment nationwide, 2) cost-effectiveness 3) easy integration with the implemented broadband infrastructures, and 4) scalability, the Femtocell technology (Thota et al., 2013) is selected and deployed as show in Figure 16.

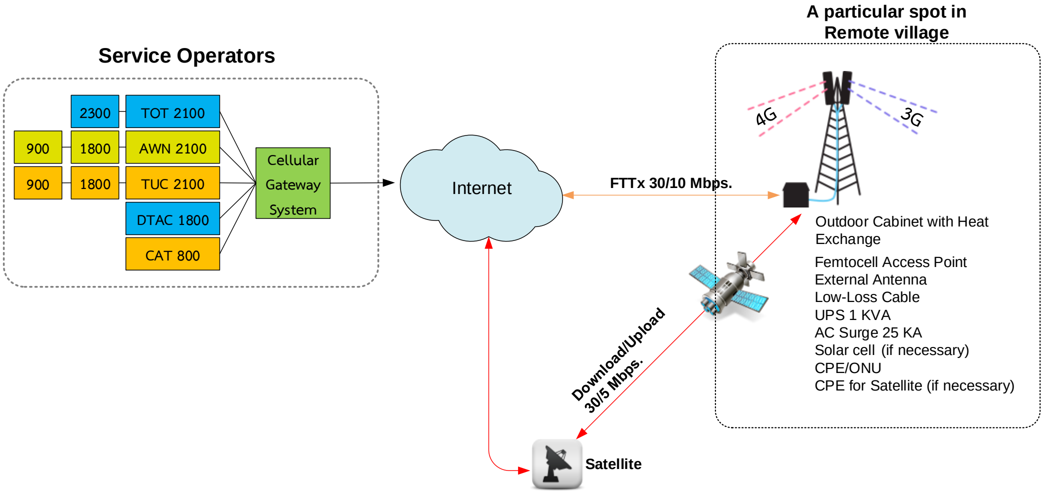
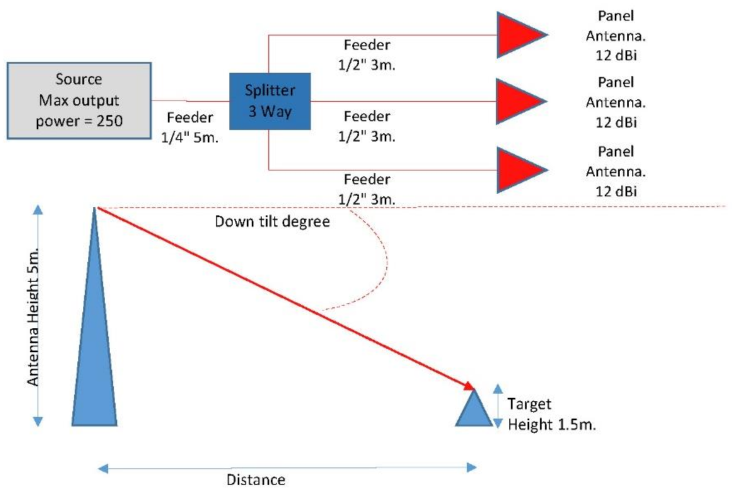


Figure 16: The deployment solution for mobile service in the remote areas.



Antenna 12dBi CPICH 10%

Link Budget		
Component	**Unit**	**Loss**
Panel Antenna	1	12.00
Feeder LL 1/4"	5	- 1.04
Feeder LL 1/2"	3	- 0.33
Connector	4	- 0.40
3 way Splitter	1	- 4.80
CPICH out of RRU (10%)		13.98
Power out of Antenna		19.41

Prediction RSCP at Distant = 100m.	
Path Loss + Obstuction Loss	97.06
RSCP at Target (dBm.)	- 77.65
Down Tilt degree	2.01

Prediction max Distant for RSCP = -77.5 dBm	
Estimate Distanct(m.)	98

Figure 17: Link budget and set a service level agreement of more than -77.5 dBm of received signal in the 100 meter-radius coverage.

In Figure 17, we calculate the link budget and set a service level agreement of more than -77.5 dBm of received signal in the 100meter-radius coverage with the usage of three 12-dBi external antennas. The designed system could be deployed within a few weeks with highly reduced cost due to the compact size of Femtocell equipment. Each such node can provide 3G/4G coverage of 100 meters at more than -77.5 dBm of received signal level and can support 16-32 concurrent users/calls. A Femtocell gateway is implemented in the service provider data center for connections and usages with service availability necessary for mobile services. With Femtocell technology, the equipment and implementation cost can reduce to approximately 150,000 baht (4,285 USD) per site compared to the cost of Metrocell (50,000-100,000 USD).

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The numerical capacity for Femtocell technology is analyzed and results show that a large number of concurrent users/calls with high quality of voice calls and internet usages can be supported with the deployed solution. Figure 18 shows a Mobile implementation and service at the particular spot.

Figure 18: A Mobile implementation and service.

4. CONCLUSION

The main objective of this research work is to illustrates new tailored last-mile technologies developed and designed to implement and establish last-mile infrastructure for rural and remote areas, called Zone C and Zone C+ respectively, in Thailand (the total of 15,732 rural and 3,920 remote villages locating around the country. The National Broadcasting and Telecommunications Commission (NBTC) has driven the government digital economy policy in order to transform these remote people and societies to enhance how to live and produce in order to reduce a digital divide existing between urban and rural/remote areas. The goal is to provide both high-speed broadband internet services and mobile services efficiently and economically in the areas with last-mile technologies designed to meet the requirements and constraints of the areas. The developed system is composed of three major parts: 1) Fixed wireless broadband services (Free Wi-Fi services), 2) Learning centers at schools and 3) Femtocell mobile services. The locations for the implementation are determined based on data collected from our survey and the calculation of an optimization problem with clustering techniques. The concluding remarks with brief discussion on some issues are:

1. For realizing sustainable social development in term of technical perspective, this study has successfully demonstrated new tailored last-mile technologies designed to implement and establish last-mile infrastructure for remote areas in Thailand. Previously, in most of the areas, there was no existing network infrastructure and services. Private network operators find it unlikely to justify the investment over that long-distance network with low population density in the areas. With this implementation, people (state authorities, stakeholders, teachers and students) in the areas can access ICT information and applications such as e-Commerce, e-Education, e-Health, etc. However, the services from this implementation have been in an earlier stage (since July 2019). Still, System performance measurement

and mechanisms are needed to be developed to make the network connections more reliable and tolerant in these types of areas. While in services, other external factors that may occur to affect the performance and consistency of network connectivity are needed to be identified and analyzed with remote and difficult terrains for transporting equipment, maintenance, and troubleshooting of the network.

2. In long term development, remote infrastructure with digital services does not guarantee the expansion of user adoption of broadband internet services in the areas. Remote areas are typically characterized by lack of skill and education. Thai government agencies have to stimulate the digital economies in the areas with community education efforts and programs in order for people to understand these new opportunities and the impact of broadband internet services on individuals, communities, and the economy as a whole. The challenge remains to understand how to maximize the advantage of the implementation in term of social assessment and economy.

3. This infrastructure implementation of the 3,920 remote villages, called Zone C+, in Thailand is the first phase of the project. According to the NBTC plan, for the second phase, the Zone C (rural areas - the total of 15,732 villages) will be considered. Technology and Infrastructure are needed to be explored to provide low-cost telecommunication in these rural areas. Initially, we learned from our survey work that 1) there are existing infrastructures by public and private network operators in most of the rural areas and 2) motivations and efforts that promote the user adoption of broadband services, personal and social benefits and ICT skills are fundamentally recommended.

5. ACKNOWLEDGEMENT

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6. DATA AVAILABILITY AND MATERIALS

Information regarding this work can be directed to the corresponding author.

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