Understanding Aboriginal Tribe Wireless Broadband Construction Trajectories Through Actor-Network Theory Views

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Abstract

A successful information and communications technology (ICT) construction project serves as a substantial reference for the promotion of related industries. However, in the past, only a few theoretical studies have been produced. Based on the network architecture of the actors, this case study attempts to explore the socio-technical interaction trajectory in Fuxing Township, Taoyuan County as an illustrative example for achieving a large-scale construction in Taiwan.

The results showed that the successful promotion of network construction in rural areas hinges not merely on technology; rather, a complex network of heterogeneous actors, including people and non-human interactors involving the political process, is crucial in shaping the achievement. Mutual benefits and conflicts of interest should be considered when the government needs to invest in fundamental infrastructure and the private sector evaluates returns on investment. Digital and internet equity is also a worthwhile topic in discussions of how government should employ limited policy tools and budgets to achieve balanced local development.

This empirical study was conducted through both qualitative and quantitative case analysis. The research therefore verified that the advantage of actor network theory lies in its comprehensive method of analysis, grounded theory for gaining insights from the views of a diverse group of actors, and use of the triple helix model of regional innovation to formulate an ecosystem to aid in the development of rural areas. Finally, we found that Actor-Network Theory (ANT) can be used as an important theoretical basis in the field of ICT construction research.

Keywords: Actor-Network Theory, Digital divide, Wireless broadband network, Rural area, Spectrum demand

1 Introduction

Aboriginal tribes and rural communities are generally located in remote areas where the development of broadband construction has long been limited due to topographic and economic factors. This study uses Actor Network Theory (ANT) to explain the success of Taiwan's tribal wireless broadband network through a story-telling mechanism. This case study can be a reference for other countries or regions which work to decrease the digital divide. Using ANT is not emphasizing the hero scenario but to describe the innovation process including success or failure context.

First, this study provides background and research questions. Bridging the rural digital divide has become an important foundation for enhancing national competitiveness. The plan to develop wireless broadband networks will make a huge contribution to narrowing the digital divide in tribal, remote, or economically unfeasible areas. Successful wireless broadband network construction is crucial, and we need to understand how this project was implemented and how it succeeded.

Next, this study introduces the theory. First, we use Callon's power translation model [1] and Law and Callon's network analysis model [2] to give an overview of ANT. Then, this study tells the story of the construction of the rural wireless broadband network in Fuxing Township and subsequent expansion of network coverage in Taoyuan County. After analyzing the whole structure through the processes of ANT, we learned from the process of ANT as a whole analysis of the structure.

The study also analyzes spectrum demands in rural and urban areas to better understand how to reallocate resources to rural areas when evaluating wireless broadband network construction by relying on evidence-based research which calculates the population, landscape, and 4G/5G spectrum demand.

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Finally, we discuss the applications of ANT and draw our conclusions. The presented study recognizes that there is still ample room for researchers to develop ANT in the field of information and communications development.

2 Literature Review

2.1 Tribal Broadband Construction is an Important Issue in the Effort to Bridge the Digital Divide

From a national development perspective, information is often expressed as a procedure or process. In his research, Roger defines informationization is a process as s a nation or ethnic group used to promote socio-economic development and transformation into an information society through the use of new ICTs [3]. However, in the process of informationization, the so-called digital gap caused by structural inequalities leads to social deprivation and new inequalities. The digital divide has been a subject of research since the 20th century, and many different approaches have been adopted to assess the quality of information, including unequal access to the Internet, the scope of use, the search for knowledge, the quality of technical linkages, and social support capabilities, and diversity of usage [4-5].

People living in rural areas, especially indigenous tribes, may have less access to ICT than people living in metropolitan areas [6]. For the rural and tribal areas, the use of ICT and mobile broadband applications will help remote villages or tribal areas overcome obstacles due to distance and bring about a new wave of prosperity. On the other hand, if the infrastructure in rural and tribal areas is not sufficiently developed due to inadequate construction or other causes, the conditions for broadband applications will lead to behind development [7].

Therefore, in recent years, government departments, enterprise, and non-governmental organizations of many countries have successively promoted measures to reduce the digital gap. Measures such as hometown communications stations [8], multi-functional information centers [9], low-cost computers [10], and digital opportunity centers have produced concrete results. The number of people without access to the Internet has been declining. But that does not mean that the digital divide issue is resolved. The continuous emergence of new technologies and applications such as wireless broadband, mobile Internet, smart mobile devices, and interactive services means that it is always a minority who first adopt and utilize these new technologies and applications. Even the users already plug into the internet access had also created a new gap from time to time.

However, the issues of a broad-based and government-supported rural infrastructure require careful consideration although there are having to get impacts, it is very difficult to accurately predict the impact on a complex political network and from any organizational processes in government structure. With the continuous introduction of new technologies and applications, the construction of wireless broadband networks should be even more considerable by influence. As a social technology, ICT is being applied to support the development of rural areas and is regarded as the key to transform [11]. Studies by scholars such as Avgerou and Walsham point out that in planning and executing ICT projects, the specific contextual characteristics of organizations, sectors, countries, and regions must be addressed [12]. Therefore, practitioners and researchers in wireless broadband networks construction must identify and support different identities in an appropriate way and as well as in the context of the political culture. To sum up, the connotation of a successful ICT project should include many significant factors [13].

In the past, information and communications systems were more likely to fail than succeed. Surveys in industrialized countries show that less than one-third of ICT projects are successfully delivered and fully meet user needs [14]. Therefore, research on the causes of the successes and failures of ICT projects is an important and practical issue [15]. Among those doing research in this field, Myers et al. have focused in particular observation of the interaction between people and technology and understood the process of success or failure [16].

This important point should be applied in discussions in the socio-technological world regarding the promotion of tribal mobile broadband deployment. Specifically, we can use the framework of tribal mobile broadband deployment to study the interaction between humans and technology. This framework of wireless broadband networks is not unique. It gives us a different perspective on the goals of many of our key stakeholders in designing wireless broadband networks. We can reflect this by rethinking the discussion of the Fuxing Township broadband network construction project. For example, the actors involved, including politicians, civil servants, research institutes and broadband operators, had different views on the technical input and output targets of the rural wireless broadband network construction project. Therefore, in the process of promotion the interaction among various actors is obvious to the ICT and the wireless broadband infrastructure in rural areas.

This study supports this idea, in other words, the form of socio-technological perspective will be applied to the analysis of tribal wireless broadband network construction. This will help to understand how actually social and technological interactions take place and what can be done, reducing the chances of failure in the planning and promotion process.

2.2 Social Technology Interaction Analysis Architecture

To answer the research questions, this study used ANT as the analysis framework. In a conceptual structure of science and technology, we observed the process of technological development and social impacts through a detailed record of innovation and development mechanisms. This study used ANT because of its wide range of applications in the interpretation, criticism, development and so on to establish and improve many important theories. In addition, ANT overcomes the limitations of technological determinism. Therefore, this study argues that ANT can be used in the complementary method for ICT systems research to avoid technical determinism as the hypothesis of the causation research between ICT innovation and the specific organization or social influence. ANT was proposed in the 1980s, mainly by scholars such as Callon, Latour and Law. The majority of past social sciences were human-centered and clearly divided "natural" and "social", "human" and "non-human". However, such an idea is not a suitable way of conceptualizing the world, because in the real world there are many actionable "nonhuman" elements [17], such as nature and matter. Latour believes that we should seek a new starting point and at the same time describe the mutual construction of society and science [18].

ANT considers this network of both social and scientific human and non-human actors as a "heterogeneous constructivism." It argues that the construction of scientific knowledge and technology is not determined only by a society (interest), but rather by a network of heterogeneous actors formed by people (society) and non-people (tools, objects, studied subjects, etc.), who decide together. In other words, ANT is a set of descriptive techniques that form, survive, evolve, and even disintegrate into the network of heterogeneous actors [19].

From the point of view by ANT, the essence of the actor is changeable, and the form of the actor is also variable, all depending on the interlinking relationships and interactions with each other. In other word ANT does not have a pre-existing framework, it regards society as a pluralistic link and was generated through the interaction between human beings and non-human beings. For example, this research study the construction process of wireless broadband networks through interaction with human and different available technologies, this can be interpreted that human and things as actors that are able to construct the final result together via actions.

As relations continuously developing, actors constantly shift in time and space to expand or change the existed network. Thence, we need to handle actors with a certain way so that actors can be stabilized as recognized "appearance". This process is known as "translation". To put it in another way, actors are possible to change their positions in time, space, shape, appearance, and essence. Actors need to present as temporary and stable identity through being translated by language and text, being conversed by interests and goals, to continue the network connection. That is, through the process of translation and transformation, the same word can have multiple meanings to display the diversity of roles and allow us to see the past invisible world [18].

The operations of translation concept are different from the research orientations. Callon proposed four translating processes, and by way of narrative trajectory, he showed how actors can make the network of actors appear through translation.

Callon pointed out that every network of actor appears by way of unique and non-repeatable events to define. The situational process for network of actor must be studied empirically according to history and network environment. The network of actors will grow up and embrace the necessary resources and persuade enough others (for example, scientific facts, technological innovations, new management practices) to support and renew the network at critical times. The process of translation consists of four steps:

1. Problematization: Actors define or redefine the starting point of the problem and identify the respective problems and objectives of key actors and other relevant actors. At this stage, three key elements—the main actors, the content of the question, and other relevant actors—must be clearly discerned. The common issue, or point, that the actors agree upon to overcome the obstacles of every actor in the network becomes the Obligatory Passage Point (OPP). Through the control of the OPP, all actors can be brought together and form a regulatory mechanism in which they move in and out of this network of operations.

2. Intéressement: Each actor has its own different goals or desired benefits. With an OPP, the actors can negotiate and coordinate with each other to achieve the best position for mutual benefit.

3. Enrollment: To consolidate and maintain cooperation among actors, the actors, through constant consultation and alliance, determine their assigned roles or positions in the network structure; alliances of partners are also shaped. Each call for mobilization is a negotiation conducted by all actors to consolidate their interests and is a process of constant error-testing until everyone reaches an acceptable solution. Actors enlist allies, usually through a series of tactics, tricks, and consultations carried out during the process [1].

4. Call for Mobilization: Each actor starts to execute according to the roles and tasks assigned to it, while one of the key actors in the network is identified as a representative of the entire operation to handle outreach. This represents a stable but not fixed cohesion, at the same time to construct a single actor of the world. It is noteworthy that the above steps do not have an end, but

constantly evolve and loop.

ANT is an open network architecture, with each actor having a different role in positioning, tasks and so on. Through the process of mutual consultation, each actor can constantly exchange positions and redefine their roles and work. Human and non-human actors can also connect with each other in the network to generate different values and results.

Callon and Law developed a network analytics model that illustrates the position of each actor community (stakeholder) against the changing landscape of technology design [20]. The analysis showed that during the various stages of planning, different networks continue to construct and rebuild. When the OPP is weakened, actors in one network can interfere with the structure and shape of another, while actors in one network can negotiate directly with actors in other networks. The actors in a network are heterogeneous, and some networks are made up of institutional actors and influential individuals, in addition, as well as geopolitical forces, technology proliferation, and social movements.

2.3 Grounded Theory for Further Data Collection and Insight Gathering

In 1967, Glaser & Strauss [21] proposed grounded theory, which is a research method that attempts to construct theoretical propositions from data analysis. Grounded theory is well suited to explain complex and not yet widely discussed social phenomena [22].

Data reliability was ensured by having all sources of data (onsite surveys, meetings with involved actors, and interviews) collected directly and crosschecked against each other during data analysis by the authors during the period of engagement in this project. In this study, the authors conduced the necessary research procedures and verified the results as well.

3 Tribal Wireless Broadband Network Construction from the Point of View of ANT

3.1 Meaning of the Case

The important analytic questions of ICT construction related research and using ANT as potentially relevant explanatory theory is how to make sure the project successfully execution. In this section, we will apply this model to the successful promotion of a tribal wireless broadband access network in Taiwan.

In face of the limited financial resources of the country as a whole, the promotion of wireless broadband infrastructure projects has mainly focused on allocating resources in accordance with policies and social priorities to promote the efficient use of budgetary resources and, once allocated, ensure the efficient use of the resources [23]. Therefore, infrastructure construction in remote areas has been given lower priority than in metropolitan areas.

3.2 Research Methods

For this study, the author directly accessed various stakeholder groups and obtained relevant documentary evidence through their role as a practitioner. Evidence includes research on documents obtained from various agencies such as proposals, results reports, and minutes of meetings; published documents such as magazines and newspapers; and interviews and observations. The extent to which these methods were used depending on the point in time of the tribal wireless broadband network project.

In this section, we will discuss the background of the tribal wireless broadband construction project and identify the actors. Table 1 shows the key groups of human stakeholders in the tribal wireless broadband construction project promotion process. It is particularly to note that the actors who is interesting to promote the tribal wireless broadband construction project not only for planners and user groups but also civil servants, media, research units and other local governments are also stakeholders

3.3 Wireless Broadband Network Construction Process

Taiwan in the remote tribal wireless broadband network was mostly set up in three phases. In the first phase, a prototype, the Broadband Network Construction Project of Fuxing Township, Taoyuan County (July 1,2013~-March 31,2014) was set up. This project was supported by the policies of the Office of the Executive Yuan's Science and Technology Commission and funded by the Science and Technology Development Fund. The commission selected tribal Fuxing Township to build a prototype wireless broadband network system.

In the coordination meeting, the Minister stated: "Fuxing Township in Taoyuan County is the first case in point. Through the improvement of the network environment in the township and the provision of tribal medical and educational services, the government has formulated a set of central and local cooperation models that can be used as a reference to implement policies to bridge the digital divide in other counties."

The project mainly consisted of two parts. In the first part, a demonstration network was established to explore aspects of technical feasibility such as fiber replacement. This network used Super WiFi rapid construction features combined with fixed lines and WiFi to create a high-coverage Internet environment in this rural area. This internal network concept means that access to information within the village does not require access from outside of Internet mode, also providing a replacement channel to watch TV instead of satellite, in the meantime to use as a private network

Table 1. Classification of key stakeholders (this study)

Group	Organization	Division	Designer	User
Central Government	Office of Science and Technology	NICI (National Information and Communications Initiative Committee)	+	
	Ministry of Economic Affairs	DOIT (Div. of Information and Technology)	+	
	Council of Indigenous Peoples	Education & Culture Div.	+	
	Other Government Units	Ministry of Education		+
		Ministry of Health and Welfare		+
	Central govt. public opinion representatives	Legislator		+
Local Government	Indigenous bureau	Managerial level	+	+
	Township center	Managerial level	+	+
	Public health bureau	Mobile health care		+
	Local public opinion representatives	Township council		+
Suppliers	Research Institutes	Information Industry Institute	+	
	Telco Company	Fixed network Div.	+	
		Mobile Communications Div.	+	
	Device Suppliers	Super WiFi	+	
Social	Media			+
	Tribes			+

for mobile health care to enhance the quality of medical care in the rural area.

Using external network and internal networks to build a complete network architecture was named i-Tribe that provided a rural broadband network application platform as well as free access to wireless broadband service for tribe members, and which was integrated with the free national WiFi network (i-Taiwan). Because it was built on the existing fixed-line broadband, Fuxing Township citizens were able to receive rich internet resources.

At this stage, Fuxing Township completed the establishment of a high altitude, deep penetration mountain tribal wireless broadband Internet access environment, mainly using Super WiFi private network technology as a safe and stable back-end network. The three tribes include the Baoling tribe of Hualaling Village at 1,200 meters above sea level, the Xuewu tribe of Gaoyi Village at 550 meters above sea level, and the Yeheng tribe of Sanguang Village at 700 meters above sea level. The overall network architecture is shown in Figure 1.

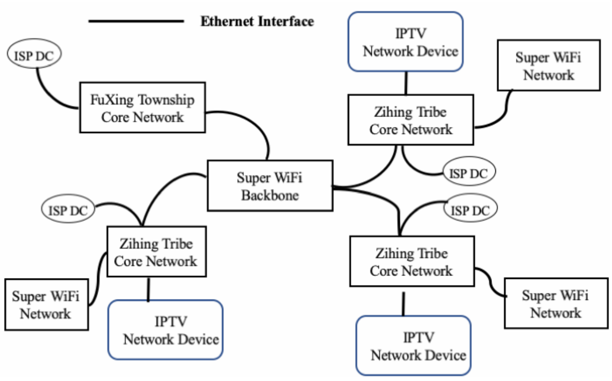

Figure 1. Fu-Xing Township Demonstration Network Architecture (Source: The original village tribe signal receiving improvement and wireless broadband system promotion plan)

This project also included TVWS (TV white space), a study of the field trial of a specialized wireless broadband network technology, whose main purpose was adopted the similar function as WiMAX, WiFi and Bluetooth wireless network equipment. No license application was required, and it did not interfere with existed users. The spectrum used was allocated for television but not used as a broadband communications spectrum. Since the spectrum is located in a lower frequency band, it has better propagation characteristics than current mobile long distance, wide coverage, and high penetration communication frequency bands, it is possible to support a better wireless broadband service in the future.

In the second phase, the coverage area was expanded to eight tribes in Fuxing Township from other three tribes and was prepared for the future nationwide expansion by Council of Indigenous People. In addition, this phase promoted the integration of a cloud multi-domain management platform as well as the cloud cross-field central network management system developed in the first phase to manage the network environments and equipment of the five tribes added at this stage. Based on the management platform of Fuxing Township, it can be gradually expanded into a national aboriginal network management center in the future.

In the third phase, we replicated the successful experience of Fuxing Township and invested in phased construction of wireless broadband networks. In October 2013, Taiwan completed operations to release its 4th generation mobile broadband service to accelerate the development of the mobile communication industry and promote the widespread use of mobile broadband services. To reach a new milestone in Taiwan's high-speed mobile broadband services, Taiwan launched a policy-driven, time-sensitive inter-departmental plan known as the Accelerated Mobile

Broadband Service and Industrial Development Plan to replicate the successful experience of Fuxing Township and extend coverage to remote rural areas of the country. Based on above two phase successful experience by the Council of Indigenous People, the goal of these 4G and wireless broadband sub-projects in remote areas was to cover at least 50% of the tribal population in three years, so that people living in rural areas would be able to enjoy the same quality broadband service as those in metropolitan areas.

The conclusion of the Policy Coordination Meeting was as follows: "The purpose of this project is to strengthen the mobile broadband environment in remote Aboriginal areas and enhance the well-being of Aboriginal people through 4G mobile communication services. The contents of the proposal are in line with the policy direction.... It is also recommended that the Council of Indigenous People should clearly plan and the collaborate with local governments and communication service providers and understand the respective positioning of everybody, and how to use the universal service fund to assist in the implementation of this case to maximize economic benefits and long-term results."

The plan was to invest 200 million NT$ dollars over three years. In 2015, 10 more tribal villages gained broadband coverage for a total of 18 villages. In 2016, 69 more were added for a total of 87 tribal villages, and in 2017, a further 70 projects were completed for a total of 157 tribal villages covered. In addition, in order to accelerate the integration of the action networks of various stakeholders, a project management center was set up to be responsible for project promotion, management and control, expansion and cross-unit coordination, and determining a site selection mechanism to set priorities for each county and city. Each stage was constructed in order, with the equipment managed and funding by the central government. The industry was responsible for building the tribal wireless infrastructure.

3.4 Network Analysis

Law and Callon's network analysis model can be used to analyze how the program achieved its goals [24]. The diagram in Figure 2 shows the degree of mobilization of the actor networks in each stage of the project promotion process in two dimensions for the passage of time, so that the translation trajectory can describe the gradual formation, stability and reform of the relevant networks.

This study borrows this model to map the support fluctuations of the central and local networks during the establishment of the tribal wireless broadband network projects.

The promotion of the network began in the center of the chart. In the beginning, the planning unit, the staff of the Office of the Science and Technology, proposed

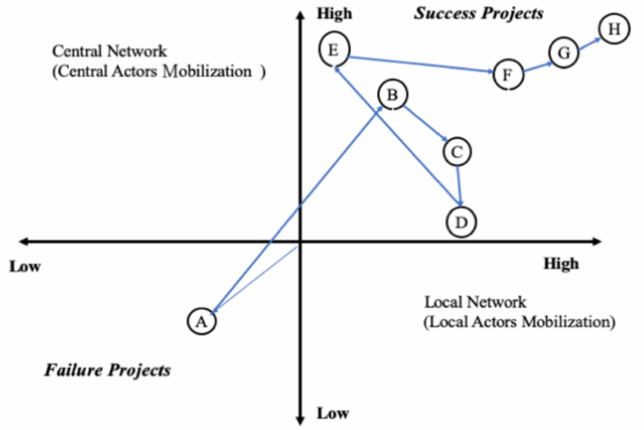

Figure 2. Network analysis of wireless broadband network projects in rural areas (drawn from this study)

a plan to build a wireless broadband demonstration network on Lanyu Island in Taitung County. The suitability of Lanyu as a model network construction site was questioned due to several issues including technical feasibility, funding, out-of-island bandwidth, computer room acquisition, local people's concerns about electromagnetic waves from wireless communication, and the scale of funding. This caused a crisis that could not be solved (A). The planning unit then proposed a revised project in which Taoyuan County's Fuxing Township was selected as the site of the project. Fuxing Township is a mountainous area with terrain obstacles that make the fixed-line broadband unreachable. Trying to use wireless technology replace fiber network, as the back-end network using wireless broadband access, the wireless broadband service will be extended to the mountainous area, while reducing the scale of the project and minimize the requirements. (B). Because WiFi was still inconvenient compared to the 3G network, local network Actors hoped that the network to be constructed would be based on the 3G mobile broadband network. It was not expected that a WiFi access network would be constructed (C). WiMAX equipment has been in development for a period of time due to Taiwan's investment in WiMAX mobile broadband networks. Through the local network, the industry hoped to construct a wireless broadband network with WiMAX as the backend network and hoped that the pilot technology would be changed (D). The central network's actors considered domestically developed Super WiFi Network technology as a fixed-line replacement for the back-end network required for a wireless broadband network. It could overcome terrain obstacles and make it easier to build networks quickly. In addition, the technology development of TVWS is potential to become a new industry opportunity. The project could successfully be promoted base on best practice, the goal of industrial development and overcoming the problems of multiple objectives for wireless Internet access in remote areas(E). Local network investment helped to solve issues with the establishment of computer rooms, relay stations, WiFi equipment, and other related facilities and power resources, enabling the demonstration project to proceed smoothly (F). The Aboriginal people took over and expanded the wireless broadband network to Fuxing Township by enrolling the actors who dispersed the local networks. Multiple tribes, extending to other tribes in other counties and cities, formed a large-area wireless broadband access network(G). The actor of central network used previous foundation as backup, maturity of network management technology and establishment of project office to promote the construction by priority in different tribes, following up promotion by central government in speed-up mobile broadband service and industrial development program. (H). The translation process is shown in Figure 2.

According to Law and Callon's method, the translation process is compared with the technical trajectory, and the positions of the groups of actors on the evolution of the wireless broadband network are drawn. Table 2 for details, including the interested, hostile, and neutral actors. The classification, as well as the drivers behind it, are based on a portion of the qualitative data collected during the author's research.

Table 2. Technical track of building a wireless broadband network in the townships (drawn from this study)

Technical Footprint	Interested Actors	Hostile Actors	Neutral Actors
SuperWiFi fixed network as backend network. WiFi as user site receiving technology. TVWS as experimental WiFi backend technology.	Office of Science and Technology (Replaced by Fiber, Fixed network) DOIT of Ministry of Economic Affairs. (Fixed network trial run, TVWS (Industry technology research)	WiMAX suppliers (Industry opportunities,WiMAX was key technology which was highly promoted by government) Local government (WiFi is not easy to manage)	Council of Indigenous People (Cost effective, workable, quick installation broadband network Fixed lines cannot reach rural areas and really need replacement solutions
3G/4G as user site receiving technology.	Tribes people (User habits)		Telco companies (3G/4G) (not enough bandwidth, lack of scale)
WiMAX fixed network technology as backend network. WiFi as user site receiving technology	WiMAX suppliers (Industry opportunities)	Department of Industrial Technology from Ministry of Economic (WiMAX was not mainstream technology)	Telco Companies (fixed line), cannot reach rural areas and really need replacement solutions

It can be shown that the technical trajectory of the wireless broadband construction process evolved in an organized manner, which was a direct result of the interaction of various actors in the network. The behavior of human actors was influenced by other entities in the network, including the technology itself. For example, WiFi wireless access technology was a low-cost wireless network. The country had a mature industrial base. The private network technology was recognized by the Ministry of Economic Affairs and considered to be an important step in the future 5G development path. When such a network solution is proposed, it is obvious that the user's usage habits are different from those of 3G/4G users. Therefore, the establishment of the tribal wireless broadband network was the successful result of interaction between the local network and the central network, become a model for building wireless broadband networks in remote areas. Without the promotion of this plan, there is no pilot test for central network with this kind of technology, and it could be used as a special requirement for adapting to network deployment in remote areas.

Further analysis of this study details the fact that in some cases, the lack of OPPs between the central and local networks could lead to the collapse of a plan to build a wireless broadband network.

In the early days of the project, there was no single point of control between the central and local networks. With no OPP, the central network operated separately from the emerging local network in the early stages of the project. When the pilot project was built over a wireless broadband network, the two networks were aggregated in an unplanned and unintended manner, resulting in a re-adjustment of the plan and the execution architecture being changed in a short period of time, as shown in Figure 3.

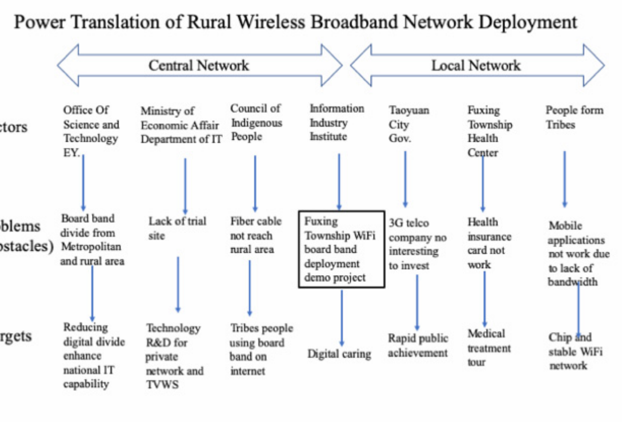

Figure 3. Wireless broadband construction plan and translation process (drawn from this study)

3.5 Tracking for Spectrum Demand

Base on the research at the Office of Science and Technology, Executive Yuan (2014-2016), the Spectrum Policing proposal, used the ITU-R M.2290 model including functionalities for demographics, user behaviors and also the Adjust User Density Spectrum Requirement Estimation Model (AUD) to fit the status of the Taiwan telecommunications market [25-26].

This research further expands on the AUD model to propose the Enhanced AUD (E-AUD) Model, which takes the following into consideration: (1) the characteristics of the Taiwan telecommunications market; (2) the minimum amount of spectrum required for individual telecommunications operators to survive; and (3) urban-rural differences in spectrum requirements. The following figure (Figure 4) illustrates the systemic framework of the E-AUD model. [25]

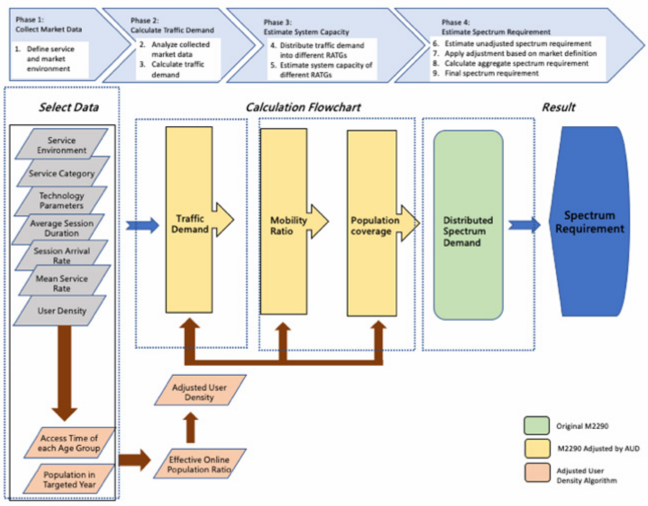

Figure 4. E-AUD model framework (drawn from this study)

Figure 4 shows part of the original ITU-R M.2290 model (ITU, 2013); the green blocks are the AUD's additional spectrum estimation components for different demographics and user behaviors; and the blue blocks are the additional E-AUD components included in this study. The new E-AUD components include: (1) a separation component for unicast and multicast service traffic in the center of the chart that better fit the separation of television/radio broadcasting and mobile broadband services in Taiwan; (2) a distribution component for non-standalone and standalone 4G/5G network traffic on the right of the chart that better fits Taiwan's technology neutral policy of spectrum management, which does not specify the use of 4G/5G technology among operators; and (3) an output component that provides the minimum amount of spectrum required for non-standalone 4G/5G or standalone 5G network services, the minimum amount of spectrum required for an individual operator to meet national demand for 4G/5G or 5G network services, and the spectrum needed for different administrative areas with different demographics and network user behaviors.

Phase 1, the collection of market data, involves radio and service environment parameters. Radio environment parameters include parameters for Radio Access Technology Groups (RATGs) such as macro cell, micro cell, pico cell, and hot spot. Service environment parameters include service categories (e.g., super-high multimedia, high multimedia, medium multimedia, low rate data, and very low rate data), data rates (e.g., high data rate and low data rate), usage scenarios (e.g., home, office, or public area), and user density (e.g., dense urban, suburban, or rural area).

Phase 2 is the calculation of traffic demand and involves two steps: (2) analysis and conversion of collected market data into market attribute settings (e.g., user density, session arrival rate per user, mean session duration, mean service bit rate [bps], and user mobility class); and (3) calculation of traffic demand (bps) based on market attribute settings.

Phase 3 is the estimation of system capacity and involves two steps: (4) distribution of traffic demand in every service category to available RATGs; and (5) evaluation of the system capacity (bps/cell) required to support the estimated traffic for different RATG services under different tele-densities.

Phase 4 is the estimation of spectrum requirement and involves two steps: (6) calculation of the original spectrum requirements for different system capacities (bps/cell) using spectral efficiency values (bps/Hz/cell); and (7) revised spectrum requirement based on the minimum amount of spectrum allocated to RATG/ISP operators and the number of operators establishing overlay networks. Then (8) aggregated spectrum requirement is calculated to get (9) the final spectrum requirement.

Calculation Formula

Select data:

- The current average cell phone access time (T_i) of each age i and population N^c
- The target population N^y in the year y
- The User Density U^y for a scenario in the year y

Result:

- Adjusted User Density $U^{y'}$ for a scenario in year y

Algorithm:

1. Find the median age (A^m) of N^c, and the corresponding average cell phone access time (T^m)

2. Calculate the weight of cell phone access time $Wi{=}T_i / T^m$ for each age i

3. Calculate the effective online population in the target year y, $N\,y' = \Sigma_i N_i y \;x\; Wi$

4. Calculate the effective online population ratio $R\,y = N^{y'} / N^c$

5. Get the Adjusted User Density $U^{y'}{=}U'{\times}R^y$ in the year y

The main idea of AUD is that the user density should be the weighted average population based on the cell phone access time of each age group population. In lines 1-2 shown in Figure 4, AUD first chooses the median age (A^m) of the population, which is not skewed so much by extremely large or small age groups, and then calculates the online access weight (W_i) of each age i. Then, as shown in lines 3-4 of Figure 4, AUD calculates the weighted average population as the effective online population N_y, and it calculates the effective online population ratio R_y as a parameter to adjust the user density. Finally, the adjusted user density U_y' is acquired by Ry and U_y in line 5. Figure 4 shows the integrated AUD/M2290 flowchart. [25]

4 Results

This study analyzed the construction of a wireless broadband network in a rural area from the point of view of ANT, mainly to provide a successful promotion for a wireless broadband network construction project as a reference for related follow-up projects. The study clearly shows that the construction of the local network was an internal political process. Actors with different interests and power bases sometimes translated their interests into drivers that influenced wireless broadband construction.

The innovative approach to the construction of the rural network was not solely determined by the attributes of the technologies involved, but also by the actors associated with the complex network, and the result of interest conflict. The application of this theory helped to determine the construction of the wireless broadband network in the local area involving the central (funding support) and local (usage) level of the network. The research clearly shows that the loss of support from the above two networks (central and local) would engender a crisis that make the project failure, and only the active and mobilized support for the two networks, could lead to the successful realization of the project goals.

The adoption of ANT helped to identify the relevant action issues to ensure the success of wireless broadband network construction. The connection between the two networks was very important. To solve the issues of the project, the OPP should be confirmed, the gradual action should be taken in the process of implementation. This means that the OPP must be identified by all actors in the network including grasp of local requirements.

ANT explains that the people how to express and represent the power. This case study of Fuxing Township's wireless broadband construction can provide industry and policy executives with a more clarified understanding of the development of wireless broadband networks in rural areas. Clear cognition is for tolerating or compromising every groups to redesign the network and to call for mobilization by potential user for network construction program, for example ease of use and the requirements of various applications.

5 Afterward and Discussion

Through the study of spectrum demand in rural Fuxing township and in metropolitan Taipei from 2016~2020, according to the spectrum resource allocation (Table 4) which may only need two operators to involve the construction investment. But based on the research results and spectrum demand calculation analysis (Figure 4, E-AUD model framework), investment in low population areas is not economically feasible.

The population density of Fuxing township (37.1 per km2) is 0.1% of the Daan (26,985.1 per km2) (a high density area of Taipei city), but the area is almost 29 times the area of Daan (Daan measures 11.4 km2, while Fuxing Township measures 330.4 km2 from original spectrum distribution comparison shown in Table 3). The spectrum demand for 5G multicasting including TV signals for Daan District and Fuxing township is 264.4 and 1891.0 respectively; for 5G unicasting without a TV signal, it is 174.0 and 90.7 respectively. In addition to after checking from the Table 4. (current sub-6 GHz spectrum resources allocated to domestic telecommunications operators, [28]), further analysis shows that spectrum distribution in rural and urban areas are not too much difference. A single spectrum operator is enough for the population in rural areas to use. Thus, to cover a large area with a low population, the operator needs to invest a great deal into the construction of broadband and mobile networks but cannot make a return on the investment. Without government subsidies, no enterprise or operator would be willing to extend coverage to rural areas or aboriginal tribes, which would limit the development of rural areas and tribes.

Recently the Taiwanese government has begun promoting the RIS (Regional Innovation System) [24] for balancing local and central government development resources and governance. It also wants to carry out revitalization in rural areas so that people will begin to leave the city and return to small towns. Many actors involved in this policy promotion, including the central and local governments, industry and enterprises, and academic institutions, have become an ecosystem for policy promotion. Figure 5 the triple helix theory of Academia-Industry-Government Relations [27] has been adopted to promote the development of local governments and local industries. Development of rural area and aboriginal tribe in mobile broadband construction can also apply the model to do the research. In this case, many actors were involved in the interaction and collaboration as well. With different propositions and benefits concern, there is not much commercial benefit in developing rural and tribal areas due to small populations and few applications which

Table 3. Comparison of spectrum demand and population density in Daan District and Fuxing Township (this study)

Year 2019	Daan District Taipei	Fuxing County Taoyuan
Population	307,631	12,259
Area (Square kilometers)	11.4	330.4
Population density	26,985.1	37.1
Take population structure into consideration(5G) = multicast = Original spectrum operation (Area)	264.4	181.0
Take population structure into consideration(5G) = unicast = Original spectrum operation (Area)	174.0	90.7

Table 4. Current sub-6 GHz spectrum resources allocated to domestic telecommunications operators Source: NCC (2019)

Operator	Spectrum allocated in the first to fourth spectrum auctions (MHz)
Chunghwa Telecom	270
Taiwan Mobile	160
Asia Pacific Telecom	85
FarEasTone Telecommunications (FET)	235
Taiwan Star Telecom (TSTAR)	110
Total	860
Operator	Spectrum allocated in the first to fourth spectrum auctions (MHz)
Chunghwa Telecom	270
Taiwan Mobile	160
Asia Pacific Telecom	85
FarEasTone Telecommunications (FET)	235
Taiwan Star Telecom (TSTAR)	110
Total	860

can generate enough APRU (average revenue per user). In this situation, strong government intervention is needed for construction projects, especially in terms of funding and negotiation with many actors.

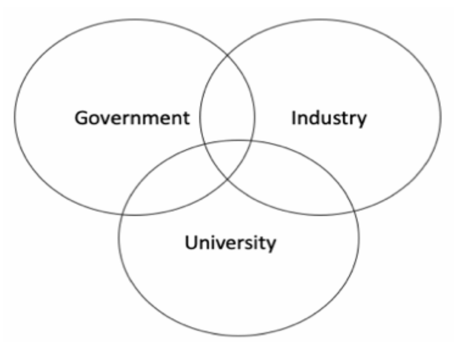

Figure 5. Triple Helix Theory of Academia-Industry-Government Relations

6 Conclusion

This study showed that the successful promotion of a wireless broadband network plan in rural areas can contribute to decreasing the digital divide. This is especially true with the successful promotion of network infrastructure design for broadband construction in areas with severe terrain obstacles. ANT can be used to provide a theoretical foundation for resolving issues that arise. Specifically, this study uses Law and Callon's network analysis model to explore the development of wireless broadband design networks project. The results show that technology is only one of several heterogeneous socio-technological elements.

The construction of the wireless broadband network, which is driven by funding from the Executive Yuan, promotes connections between the central and local networks. The use of spectrum demand analysis provides evidence-based quantitative data to explain the gap in development between rural and urban areas and to aid in the appropriate utilization of limited resources in policy promotion.

This study verifies that ANT can be used in wireless broadband and 4G/5G construction policy decision-making. The identification of stakeholder groups in the process of network construction can provide researchers with an understanding of interactions between these groups, between people and technology, which helps to grasp the communication construction trajectory. Therefore, it can be used to solve various research issues in the development of information communication.

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