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## Article

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# Practical mobile network planning and optimization for Thai smart cities: Towards a more inclusive globalization

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## ABSTRACT

Globalization has facilitated productivity gains and economic growth and for decades. It has helped integrate emerging economies, spread technology, knowledge, culture, and created an interconnected global community. Smart cities depend on a robust and flexible mobile network foundation, and yet, Thailand is leading the way in the ASEAN. Using Thailand as a case study, this paper presents a practical mobile network planning and optimization framework (PMNPO) that's workable for the fourth-generation up to sixth-generation networks in smart cities, especially in an industrial estate. While theoretical frameworks play a vital role in optimizing network performance, such frameworks may not be practical enough. This study applies a mixed quantitative research method on actual applications (case studies) and qualitative research. The PMNPO is a management function of pseudo-codes. A workable cost-sharing model for mobile networks consists of CAPEX, OPEX, feasibility study, and site value management (mobile network operators). The fair factor (0.2), the payback (5 years), the NPV (\$0.5 million), and the IRR (20%) reveal a promising financial prospect. The PMNPO is practical for Thailand, with a mean acceptance rate of 4.83. Therefore, the findings support stakeholders, policymakers, and decision-makers, in setting telecommunication policies. The results can apply to other developing countries or catalyze a similar research type.

## Introduction

The Thai government has been focused on developing the digital economy and society to enhance the Thai economy. An initiative on smart cities is one of the Thailand 4.0 endeavors to support the Thai digitalization ecosystem, aiming to transform Thailand into a developed nation by 2037. The smart city initiative is expected to cover 100 cities in 77 provinces by 2023 (Ministry of Digital Economy and Society, 2019). Accordingly, a smart city joins the social, physical, business, and information and communication technology (ICT) infrastructures to control the shared intelligence (Fang, Qian, & Hu, 2017). Thus, a mobile network (MN) or radio network (RN) is one of the backbones of smart cities.

Like other countries, mobile network operators (in this study, referred to as "operator(s)") in Thailand are facing a fall in revenues. Modern internet-based services are now substituting traditional telecommunication services. The growth in data usage is increasing the operational cost of the operators (Lähteenmäki, Hämmäinen, Zhang, & Swan, 2016). Fifth-generation (5G) and coming sixth-generation (6G)

networks require a high volume of small cells and microcells due to a higher bandwidth (Oughton & Frias, 2018). A techno-economic framework for 5G networks is needed (Yaghoubi et al., 2018). It is envisaged that appropriate infrastructure-sharing is the key to minimizing the 5G/6G network rollout cost. While the cost model of 5G and fourth-generation long-term evolution (4G-LTE) networks may have been previously published (Oughton & Frias, 2018), a model of infrastructure-sharing cost such as co-towering is rarely reported.

### *An industrial estate, a "smart and sustainable city"*

The "industrial estate" was selected for this research. It is a complete industrial town located in the "Bangkok Metropolitan Region" (BMR), Thailand. The industrial estate plans to transform itself into a "smart sustainable city" (SSC). Its vision is to be the industrial city of innovation. The mobile signal will need to cover all areas. The industrial estate is to select the appropriate locations for site installations with the most cost-effective solution. There is a limited amount of land for greenfield tower installations. This poses technical and cost model challenges.

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Three operators are currently operated within the area.

The industrial estate is a complete self-sustainable industrial town in the BMR (2,600 acres, home to 200 companies and 150,000 residents). The industrial estate was established in 1971. The industrial estate has its public utility services: power substations, compressed natural gas, water supply, wastewater treatment system, telephones, high-speed internet, roads, security systems, and solid waste disposal.

The current and future state (needs assessment) was undertaken through in-depth interviews with the key stakeholders (Nyanchoke, Tudur-Smith, Iversen, Tricco, & Porcher, 2019). The stakeholders consisted of the industrial estate owner and the executive members of telecommunication companies (telco) and operators. The identified problems were the availability of land, the co-sharing of infrastructure between operators, and the ownership. From the owner's view, it was not possible to facilitate each operator with its towers. The telcos were to invest in the infrastructure, pay the cession, and lease out these infrastructures. Operators are responsible for site value management (SVM). A site priority zone issue needs to confirm with the Office of the National Broadcasting and Telecommunications Commission (NBTC). There is a need to model the techno-economic of co-towering for practical contribution.

### *Our contributions and significance*

This paper presents a practical mobile network planning and optimization framework (PMNPO) with management functions designed for SSCs that cater to the 4G up to 6G networks. The PMNPO has been applied to the actual case studies via quantitative research. It presents the infrastructure cost-sharing among operators, including the capital expenditure (CAPEX) and the operational expenditure (OPEX), with the actual case studies accepted by all participants (owner, telcos, and operators) via qualitative research. The proposed framework is a techno-economic framework for 4/5/6G implementation focused on SSCs.

The paper makes both theoretical and practical contributions. The first is that the PMNPO is practical and a workable approach to NPO by including the management functions (pseudo-codes); see Appendix A. The second is that the relationship among planning, optimization and cost modeling are presented in a real-case approach. The third is that the MN implementation issue in SSCs is improved by introducing infrastructure-sharing among operators with the cost-sharing model and a proposed fair factor (F) formula, which is a management model for SSCs. The fourth is the SVM in the operators' views which has not been explicitly mentioned in the traditional telecommunication theory (Laiho, Wacker, & Novosad, 2006; Rahnema & Dryjanski, 2017).

The point to be noted here is that designing mobile networks for a new industrial estate or smart cities is not as difficult as the existing ones. However, there are dimensions for the network designer that must resolve in the existing cities, such as land availability, density, and sustainable business model (consensus among owner, telcos, and operators).

### **Literature review**

#### *Smart and sustainable cities, a knowledge gap?*

Nearly \$80 billion was invested in smart cities across the globe by policymakers, and yet, it was spent solely on smart technologies. According to Mondschein, Clark-Ginsberg, and Kuehn (2021), the main challenges in deploying these technologies were organizational, not technological. While the importance of sustainability concepts in smart cities' development has been reported (Khan et al., 2020), only a few studies were focused on the managerial and operational aspects of mobile network planning and optimization (MNPO) in smart cities. From a Thai standpoint, a smart city is equivalent to a "smart sustainable city" (Pornwasin & Ganjanakhunde, 2018).

A literature survey was conducted on smart cities and other relevant

domains. Nonetheless, the big picture diagram on MN in smart cities was often incomplete, especially management function (a cost-sharing model due to a space limitation). The theoretical frameworks and the existing literature were impractical in the actual implementations (Boukerche, Coutinho, & Loureiro, 2019; Hakiri & Gokhale, 2018; Raissi, Yangu, & Camps, 2019; Rusti, Stefanescu, Ghenta, & Patachia, 2018; Rusti, Stefanescu, Iordache, Ghenta, Brezeanu, et al., 2019; Rusti, Stefanescu, Iordache, Ghenta, Patachia, et al., 2019; Stan, Gheorghiu, Nemtanu, & Iordache, 2018; Tzortzakakis, Papafotis, & Sotiriadis, 2017). In the last decade, the theoretical network planning and optimization (NPO) frameworks were intended to optimize the network performance (Basit, 2012; Chimmanee & Jantavongso, 2016; Eisenblatter, Geerdes, & Grottschel, 2008; Hasnat, Rurnee, Razzaque, & Mamun-Or-Rashid, 2019; Laiho, Djupsund, Korteniemi, Grandell, & Toivonen, 2006; Laiho, Wacker, et al., 2006; Mishra, 2018). However, most literature was focused mainly on the optimization algorithm (Ceselli, Premoli, & Secci, 2017; El-Beaino, El-Hajj, & Dawy, 2015; Georgiev, Bakr, Ali, & Al-Mutawaly, 2015; González, Hakula, Rasila, & Hämäläinen, 2018; González González, Mutafungwa, Haile, Hämäläinen, & Poveda, 2017; Pérez-Romero, Sallent, Ferrús, & Agustí, 2016; Prasad, Rath, & Simha, 2014; Sandoval, González, Hämäläinen, & Yoo, 2016; Tsoulos, Athanasiadou, Valavanis, & Zarbouti, 2017). Those publications were concentrated on technological challenges such as the internet of things (IoT), long-range (LoRa), low-power wide-area network (LPWAN), the application layer of 5G technology, and network design.

#### *Facilitating mobile network planning and optimization for smart and sustainable cities*

A typical mobile network planning (MNP) begins with gathering input parameters, for example, capacity, coverage, and quality. These input parameters create the theoretical coverage and capacity plans. The coverage optimization goal is to maximize the coverage and reduce costs (Eisenblatter et al., 2008). The forecast demand for services should be satisfied in capacity planning.

The main MNPO challenges in SSCs are not technological aspects. Instead, ICT infrastructure support, speedy urbanization, lack of government wisdom, lack of coordination and externalities, partnerships, and sustainable smart cities implementation issues were the challenges for SSC's development (Khan et al., 2020). Moreover, the authors draw on the existing works from science, technology, economic, socio-technical studies. Eleven fields were identified. They are organizational, institutional, and technological processes. The key findings were summarized into a table format (Cherdantseva et al., 2016; Galvan & Galvan, 2017; Hemanidhi & Chimmanee, 2017), see Table 1. Nevertheless, the theoretical findings did not reveal the complete practical procedure. Therefore, the initial results support the authors' assertion that the total practical procedure and the big picture diagram are needed, especially in SSCs.

The existing literature revealed more toward theoretically-based studies of MNPO, for example, radio-frequency planning and optimization, mobile network optimization, mobile network planning (MNP). The practical procedures, especially in a smart city such as the cost-sharing infrastructure model and the SVM, had rarely been found (Abuibaid, 2016; Basit, 2012; Chimmanee & Jantavongso, 2016; Eisenblatter et al., 2008; Laiho, Djupsund, et al., 2006; Laiho, Wacker, et al., 2006; LIME, 2009; Rahnema & Dryjanski, 2017).

The findings revealed the works on the optimization algorithm. The existing MNPO studies were focused on coverage (Sandoval et al., 2016), design (Ceselli et al., 2017), implementation, (Chimmanee & Mahuwan, 2018), location (Georgiev et al., 2015; González et al., 2018; González González et al., 2017; Prasad et al., 2014), and power optimization (Pérez-Romero et al., 2016; Tsoulos et al., 2017). Received signal strength indicator (RSSI), round-trip time (RTT), and packet loss rate were used to measure the mobile network performance (Khan et al., 2020) both in moving and stationary environments (Ahmad et al., 2019;

**Table 1**

Existing mobile network planning and optimization studies.

	Domains										
	Theoretical	Optimization	Performance	Service	Cybersecurity	Machine learning	Cost model	Smart cities	IoT	5G	6G
Abuibaid (2016)	x										
Basit (2012)	x										
Chimmanee and Jantavongso (2016)	x										
Eisenblatter et al. (2008)	x										
Laiho, Djupsund, et al. (2006)	x										
Laiho, Wacker, et al. (2006)	x										
LIME (2009)	x										
Rahnema and Dryjanski (2017)	x										
Ahmad et al. (2019)					x					x	
Fang et al. (2017)					x					x	
Hasnat et al. (2019)					x					x	
Ahmed (2013)			x								
Chimmanee, Jantavongso, and Kantala (2015)			x								
Dong, Du, Zheng, and Zhang (2015)			x								
Jantavongso and Chimmanee (2019)			x								
Al-Eryani and Hossain (2019)										x	x
Allam and Dhunny (2019)								x	x		
Hakiri and Gokhale (2018)								x	x		
Azman, Panicker, and Kashyap (2019)							x	x	x		
Boukerche et al. (2019)								x		x	
Rusti et al. (2018)								x		x	
Rusti, Stefanescu, Iordache, Ghenta, Patachia, et al. (2019)								x		x	
Bruce, Wittgreffe, Potter, and Robson (2005)				x							
Goncalves, Miranda, and Cercas (2007)				x							
Mazhelis, Tyrvaenen, and Viitala (2007)				x							
Wong (2015)				x							
Ceselli et al. (2017)		x									
Chimmanee and Mahuwan (2018)		x									
El-Beaino et al. (2015)		x									
Georgiev et al. (2015)		x									
González et al. (2018)		x									
González González et al. (2017)		x									
Prasad et al. (2014)		x									
Sandoval et al. (2016)		x									
Tsoulos et al. (2017)		x									
Fialho and Fortes (2019)									x		
Tzortzakos et al. (2017)									x		
Huang et al. (2019)						x					x
Letaief, Chen, Shi, Zhang, and Zhang (2019)						x					x
Tang, Kawamoto, Kato, and Liu (2020)						x					x
Knoll (2014)							x				
Lähteenmäki et al. (2016)							x			x	
Lombardo (2019)							x			x	
Nikolij and Janevski (2015)							x			x	
Oughton and Frias (2018)							x			x	
Smail and Weijia (2017)							x			x	
Yaghoubi et al. (2018)							x			x	
Nazarenko and Safdar (2019)					x					x	
Pérez-Romero et al. (2016)		x				x				x	
Raissi et al. (2019)										x	
Rusti, Stefanescu, Iordache, Ghenta, Brezeanu, et al. (2019)										x	
Rappaport et al. (2019)											x
Stan et al. (2018)								x			
Taweesaengsakulthai, Laochankham, Kamnuansilpa, and Wongthanavasu (2019)								x			

Chimmanee & Mahuwan, 2018; Dong et al., 2015; Jantavongso & Chimmanee, 2019).

The application of 5G within smart cities was reviewed. Rusti et al. (2018) proposed the theoretical concept for a network-aware smart city's 5G cloud-native application with a three-layer architecture. Rusti, Stefanescu, Iordache, Ghenta, Patachia, et al. (2019) introduced the smart architecture based on 5G that collaborates autonomous cars and urban devices.

In the case of Thailand, Taweesaengsakulthai et al. (2019) reported a national policy for the social and economic development in Chon Buri, Phuket, and Bangkok. The application layer of 5G, network architecture, network design, cyber-physical system (CPS), in-field technology, IoT, the testbed deployment, and onboarding process of application components on MATILDA and SliceNet were reviewed (Azman et al., 2019; Boukerche et al., 2019; Fialho & Fortes, 2019; Hakiri & Gokhale, 2018; Raissi et al., 2019; Tzortzakakis et al., 2017).

As mentioned earlier, the cost model lies at the heart of this study. It consists of the techno-economic, cost analysis, forecast model, and mathematic cost model. For example, Yaghoubi et al. (2018) presented a case study on a backhaul-based transport segment. It reported that a deployment solution with the lowest total cost of ownership (TOC) does not always lead to the highest profit. Knoll (2014) emphasized the detailed techno-economic model with the inherent coupling of CAPEX and OPEX. Lombardo (2019) forecasted that the future OPEX and CAPEX of the 5G network would be dependent on the required network capacity. Smail and Weijia (2017) proposed the pricing model for migrating 4G to 5G.

The service monitoring and operations support systems (OSS) were commonly used by the operator's back-office (Bruce et al., 2005; Goncalves et al., 2007; Mazhelis et al., 2007). Implementing the OSS model to monitor mobile networks using key performance index (KPI) remained an important issue for mobile network monitoring.

The 6G technology is expected. The future of the mobile network will be dependent on 6G. This involves ubiquitous 3D coverage, a network protocol stack, and pervasive artificial intelligence (AI). The 6G potential technologies will allow AI-enabled methodologies and mobile AI applications (Letaief et al., 2019). In addition, the 6G network will introduce the issues of high mobility, heterogeneous structure, large scale, privacy, and real-time (Tang et al., 2020).

In summary, this section introduces the knowledge gaps, a review of theoretically based MNPO, the existing studies on an optimization algorithm, the methods of mobile network performance, the mobile network in smart cities, cost models, the cybersecurity issues on 5/6G, the service monitoring, OSS, and finally, the 6G potential technologies. The findings allow the authors to identify relevant theories, methods, and gaps in the existing research.

## Methodology

### Conceptual model development

The conceptual model comprises two independent variables:

planning and design (PD) and optimization (OPT). Traditionally, MNP creates a cost-effective solution that obtains maximum coverage at a minimum cost (LIME, 2009). MNP is needed to control high costs for building infrastructure and provide high-quality services (Eisenblatter et al., 2008). For this reason, KPI-satisfy and cost-effective factors are the dependent variables (Fig. 1). The mixed-method is divided into three steps (Fig. 2). The first is qualitative research employing in-depth interviews. The second is quantitative research using the actual case studies (experimental research) to prove the initial model. The final step is qualitative research using focus group discussions and in-depth interviews.

Since this paper focuses on the planning and optimization framework, the implementing factor is the extraneous variables (non-study variables) (Fig. 1). The variables are expressed in terms of equations (Insombat, 2015); see (1) and (2). The PMNPO is based on the studying of such variables (Fig. 2).

$$PD = \int (KPI \text{ satisfy, cost - effective}) \quad (1)$$

$$OPT = \int (KPI \text{ satisfy, cost - effective}) \quad (2)$$

The mixed-method was adopted into three steps. *Step 1* is qualitative research using in-depth interviews to produce the initial network optimization model in *Step 2* (quantitative research using experimental). *Step 3* divides into the feasibility study, cost modeling (first session), and technical framework (second session). Finally, *step 3* improves the initial model using focus group discussions and in-depth interviews. The integration of knowledge from *Steps 1, 2, 3*, and the literature synthesizes the PMNPO.

The interviews gathered the opinions of the experts on the initial model and the refinement model. In addition, a large-scale purposive sampling of the Thai experts was collected. In total, thirty-nine in-depth interviews were carried out in February 2018–20. These experts consisted of four telcos, fifteen system integrators, thirteen operators, four developers from the industrial estate, two academics, and a regulator.

### True experiment (first case - temporary solution)

The first case is a true experiment. It was applied to the graduation ceremony in Bangkok. Users expect the same level of service quality in a mass or temporary event. The operators must guarantee their service performance and quality level. Efficient resource allocation between users is vital.

**Problem:** The graduation ceremony was selected to illustrate the initial model on network optimization of 4G services. The event set a high requirement on the network due to the many users in the limited area. It is difficult for the operators to meet this temporary high-rate and high-level demand. The service quality is affected by the rapid increase in the number of users accessing the services in a relatively short time.

**Target:** To develop and evaluate the initial model on MNPO in a temporary event.

**Information:** It was a two-day event held on 10–11 November 2018.

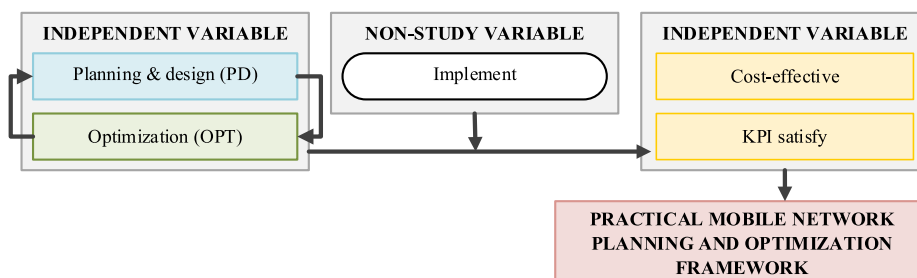


Fig. 1. Variables of this research.



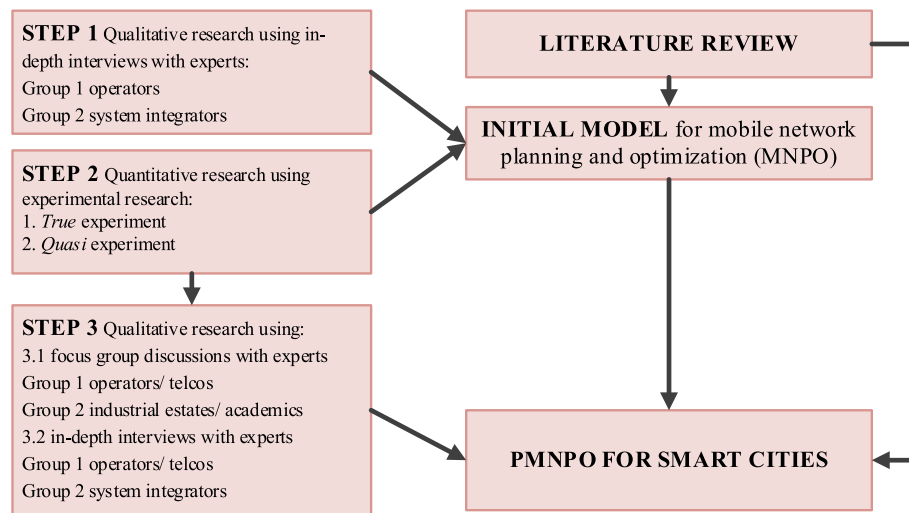


Fig. 2. Research conceptual framework.

The ceremony took place in Bangkok. Seven thousand participants were estimated. The site was surveyed before the event. There were three BSs in the area (Fig. 3). Stations A and C both already had a high utilization (75–100%). Station A was located closest to the event (approximately 500 m), but the university's buildings blocked the signal. Station C was located within the high-density residential area. In contrast, Station B had a lower utilization with a 25–50% (yellow) and 50–75% (green) utilization. Station B was on the main road and unlikely to provide adequate services during the busy hours.

**Methodology:** Design and implement BSs to optimize the network performance in a temporary event. This involves proving the model by interviewed the experts and conducted the field tests.

#### Quasi-experiment (second case - permanent solution)

The industrial estate is the first industrial estate in Thailand since 1971 and a complete industrial town in the BMR with 2,600 acres, home to 200 companies and 150,000 residents.

**Problem:** There were requests from users and operators. The operators were to upgrade their services by establishing the new sites. The

industrial estate is to transform itself into a smart, sustainable city with a limited land area. Network signal is required to cover all areas of the industrial estate. A cost-effective solution was needed.

**Target:** To discover the most cost-effective solution allowing the existing operators to operate at the industrial estate. The solution must support 4/5G and future technologies.

**Information:** It is a quasi-experiment (Phengsawat, 2014). Three operators were operated in the industrial estate (Operators A, B, and C). The existing nodes are listed in Table 2. The attention was on the industry zone – i.e., the number of greenfield towers and their locations. The total number of greenfield towers was fifteen. The sites are

Table 2

Existing mobile node devices of the operators in the industrial estate.

Operator	Greenfield	Rooftop	IBC*	Small cell	Total
Operator A	9	16	13	24	62
Operator B	3	5	–	–	8
Operator C	3	4	–	–	7

\* in-building cellular.

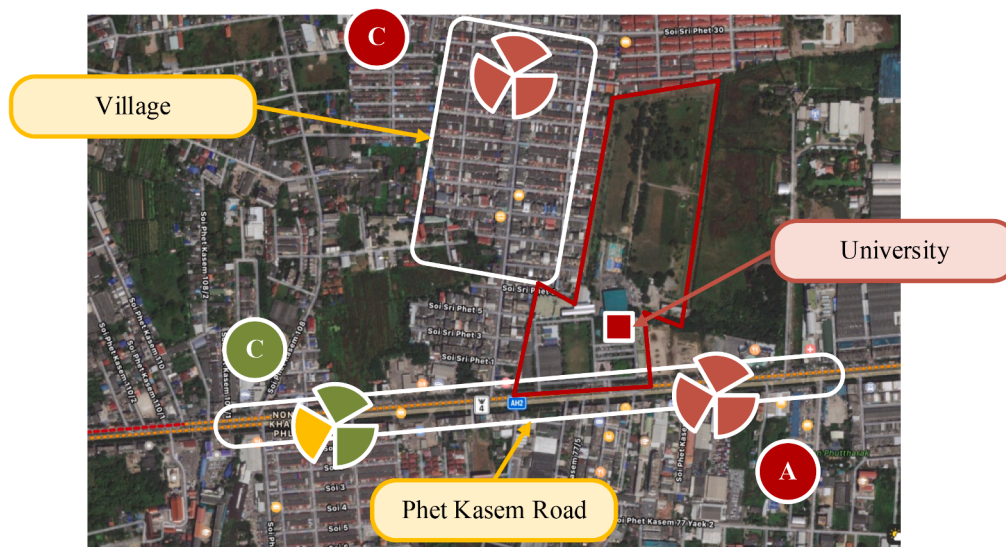


Fig. 3. Location of the field test. Three BSs are located within the vicinity of the university. (Stations A and C, denoted by the red sector, represent high utilization. The yellow and green sectors indicate both low and medium utilization, respectively.) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

displayed in green, red, and blue dots (Fig. 4).

**Methodology:** The operators completed the PD and implementation processes because the networks have existed. The procedure was started from the OPT process as follows. *Step 1* was to initiate the optimization process. *Step 2* dealt with the network performance monitoring (NPM). *Step 3* covered the field measurements. *Step 4* tuned the parameters. Finally, *Step 5* was related to the re-planning.

The towers that belonged to the various operators were closely situated to each other (Fig. 5). For example, Fig. 5 (a) displays the location of greenfield towers belonged to Operators A and B, while Fig. 5 (b) depicts the greenfield towers belonged to Operators A and C that are nearby to each other.

#### Cost model

In contrast to the previous studies on cost models (Lombardo, 2019; Nikolikj & Janevski, 2015; Oughton & Frias, 2018), the proposed cost-sharing model concentrates on the co-shared tower. Therefore, the cost-sharing model can apply to the existing cost models and future technologies. Since each tower-sharing is in the range of 1 to 3, the maximum number of operators should be three. The cost model for calculating the rental for each tower-sharing was presented.

The average rental of tower-sharing,  $Rent_{avg}$ , is estimated using (5).

$$Total\ project\ cost = Total\ rental \div IRR \quad (3)$$

$$Total\ rental = Total\ project\ cost \times IRR \quad (4)$$

$$Rent_{avg} = (Total\ project\ cost \times IRR) \div (12 \times Total\ tower) \quad (5)$$

where

$Total\ project\ cost$  is the total project investment cost with CAPEX and OPEX.

$Total\ rental$  is a sum of the rental fee from all the tower-sharing.

$IRR$  is the internal rate-of-return (IRR).

Weight for fair cost-sharing at site  $i$ ,  $W$ , can be found using (6).

$$W_{(i)} = 1 - [0.2 \times (N_{(i)} - 1)] \quad (6)$$

The actual rental fee (multi-operator rental,  $MRent$ ) is estimated using (7).

$$MRent_{(i)} = Rent_{avg} \times W_{(i)} \quad (7)$$

where

$N$  is the number of operators who rent the same tower at  $i$ .

$W$  is the weight fair cost-sharing for the tower-sharing at  $i$ .

$F$  is the fair factor in a range of 0.1–0.99. The default value is 0.2.

Total incoming from rental can be found using (8).

$$Total\ MRent_{(n)} = \sum MRent_{(n)} \quad (8)$$

An explanation of the proposed cost-sharing model can be found in Section 4. Besides, financial criteria are the ideal method to assess projects. These models are suitable when there is a high level of assurance regarding the forecasted cash flows. Two models are payback and net present value (NPV). The payback model deals with the time it will take to recuperate the project investment. Shorter paybacks are preferable. Payback is the most adopted model. The payback formula is as follows.

$$payback(yrs) = estimated\ project\ cost \div annual\ savings \quad (9)$$

The NPV model applies a minimum anticipated IRR (discount rate) to calculate the present value. If the finding is positive, it is qualified for further attention. If the result is negative, the project is dropped. Hence, a higher positive NPV is preferable (Larson & Gray, 2018).

$$NPV = I_0 + \sum_{t=1}^n \frac{F_t}{(1 + IRR)^t} \quad (10)$$

where

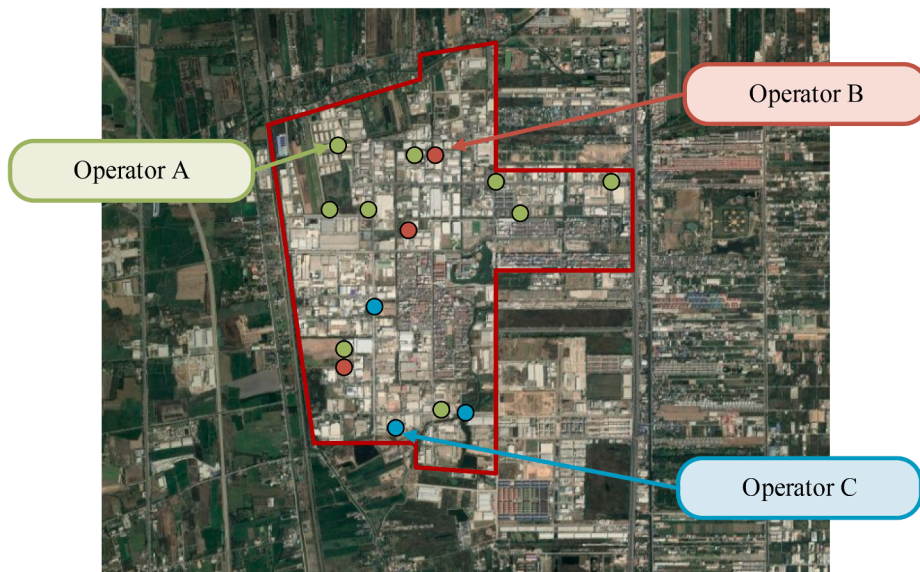
$I_0$  = Initial investment (since it is an outflow, the number will be negative)

$F_t$  = Net cash inflow for period  $t$

$IRR$  = Internal rate-of-return

#### Site value management

SVM has not been explicitly mentioned (Laiho, Wacker, et al., 2006; Rahnama & Dryjanski, 2017). SVM is defined according to the operators' views. An MNP engineer decides on the site priorities based on the given budget and other factors. A value is a ratio between the derived benefits from the site and the associate costs. The financial return is the most important factor from the operators' opinions. The return on investment (ROI) and payback demonstrate sufficient economic justification. Providing access to services with the least spending creates a



**Fig. 4.** Location of towers of Operators A, B, and C. (Fifteen dots represent the greenfield towers belonged three mobile network operators within the industrial estate. Green dots refer to Operator A, red dots are Operator B, and blue dots are Operator C.) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

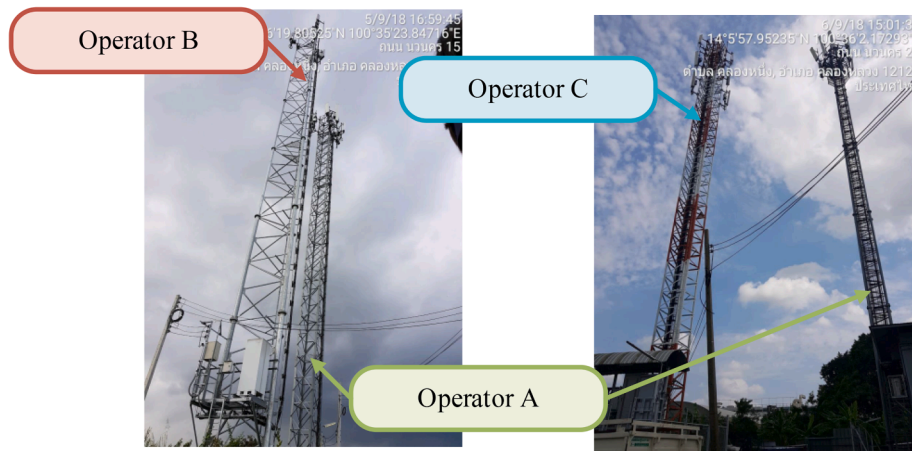


Fig. 5. (a) The location of towers belonging to Operators A and B; and (b) Operators A and C were next to each other.

chance for the operators to maximize the ROI. A network plan is vital to install and keep a flexible and adaptable network. The SVM for the new site is needed to understand the impacts in all aspects: a guarantee of a safe environment for the public, the complete process of tower construction and operation, etc.

## Results

The guideline of the MNPO model was developed. The experts identified nine steps for locating a suitable site for the BSs as follows: (1) perform a demand analysis on the service area and the data traffic; (2) plan the installation according to the site; (3) analyze and estimate the cell size and the noise effect; (4) send a surveyor team to explore the location; (5) conduct drive or walk tests to locate the best fit site; (6) finalize the frequency and the location for the BSs to be installed; (7) install the BSs; (8) adjust the system; (9) repeat the first step when there is a change in demand, or additional BS is needed.

Fig. 6 demonstrates the practical solution in the temporary event. The network is expected to cope with the temporary high service

demand. The network must be optimized to satisfy the need of the users. Moreover, drive or walk tests generate the performance statistics such as reference signal receive power (RSRP), throughput, and physical cell identity (PCI). The tests provide a sense of the in-the-field experience of the network. The optimization process consists of monitoring and improvement of the network performance. The optimization of service quality is an ongoing process. The optimization process can be initiated with the network improvement plan, the complaint, or the extra capacity request. The modification of tilts, azimuths, antenna height, and performance parameters are part of the RF optimization process.

### Results of case 1 (true experiment - temporary solution)

The site was surveyed before the event (Fig. 3). Stations A and C had a high utilization. Station A was located closest to the event, but the buildings blocked the signal. Station C was in a high-density residential area. Despite having a lower utilization, Station B was on the main road and unable to provide adequate services during the busy hours.

The solution was to install the portable BSs in two locations within

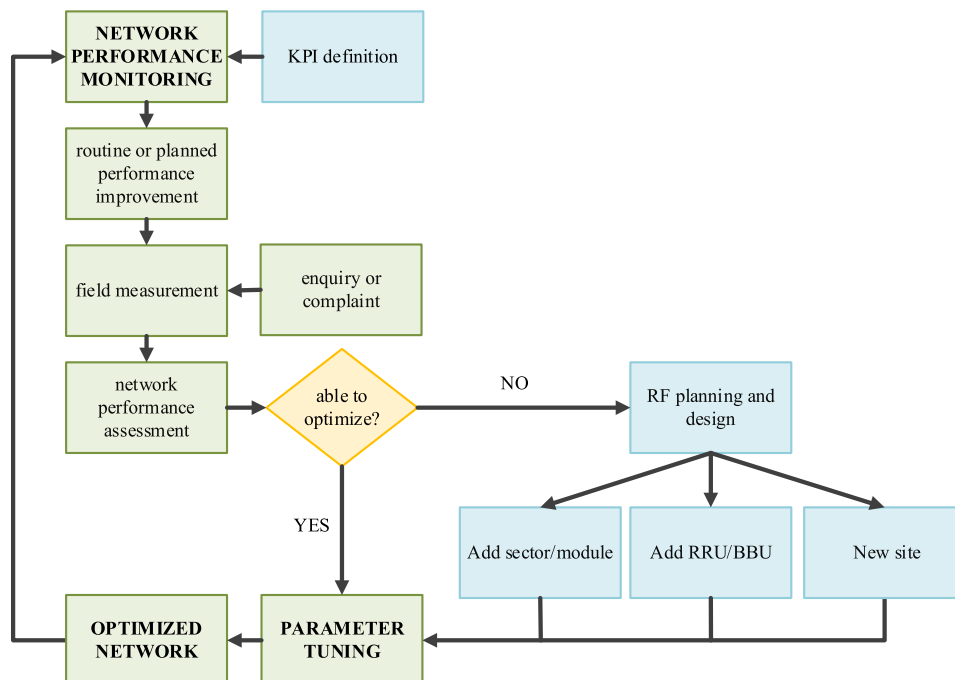


Fig. 6. The guideline of the MNPO model.



the university at the soccer ground (Node 1) and the cafeteria (Node 2), see Fig. 7. Each BS consisted of one node and three sectors. The sectors of Node 1 were set the antenna azimuths as 60, 180, and 300 degrees clockwise from the north. The sectors of Node 2 were set the antenna azimuths as 90, 210, and 300 degrees. The number of degrees was set according to the terrain, environment, and signal strength during the installation.

Before the nodes' installation, the latency (ping) tests reviewed the average time to the domestic and foreign websites in milliseconds (ms). It took 31.1 ms to ping the domestic website. For the foreign website, the average value was 44.6 ms. This is compared with 19.5 ms (domestic) and 25.7 ms (foreign) after the nodes' installation. The findings of the speed tests before the nodes' installation indicated that the average receiving data rate (DL) was 48.3Mbps, and the average transmitting data rate (UL) was 27.2Mbps, compared with 89.4Mbps (DL) and 38.9Mbps (UL) after the nodes' installation.

#### Results of case 2 (quasi-experiment - permanent solution)

Operator A had the most extensive coverage area. Operators B and C were similar in terms of the coverage area. The existing network performance was to be improved to cover the industrial estate. The parameter tuning (PT) (Step 4) in the OPT process was unable to satisfy the KPI definition (Section 3). Therefore, it went back to the re-planning (Step 5). The PD process was taken, and eleven greenfield towers with appropriate locations were needed (Fig. 8). This would enable the coverage area to be satisfied. The detail of the design process is beyond the scope of this paper. Two possible solutions are as follows.

**Solution 1** is to provide additional towers for each operator. For example, operator A had nine greenfield towers, Operators B and C had three greenfield towers each (Table 2). Therefore, Operator A needs to add at least two greenfield towers, Operators B and C need to add at least eight greenfield towers each. Additionally, the industrial estate needs to provide additional land for installation at least eleven sites ( $11 \times 3$ ). The greenfield tower cost is \$64,643 each. The land rental is \$389 per month per location.

**Solution 2** is for the industrial estate to provide eleven towers for the three operators. The industrial estate will expropriate all existing greenfield towers. From the technical design perspective, two additional greenfield tower sites are required. Following this, the current operators need to rent the greenfield towers from the industrial estate. Referring to the cost-effectiveness (Fig. 1), the second solution is preferred for both the industrial estate and the operators.

#### Application of the cost model

The tower's minimum number is eleven, and the total CAPEX value is \$709,650 (Table 3). The focus group discussions were conducted to obtain the F value (Fig. 9).

This section demonstrates the equations applied to this case (Section

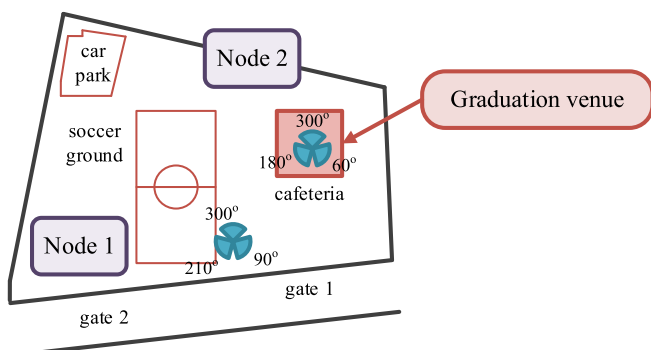


Fig. 7. Locations of portable mobile BSs.

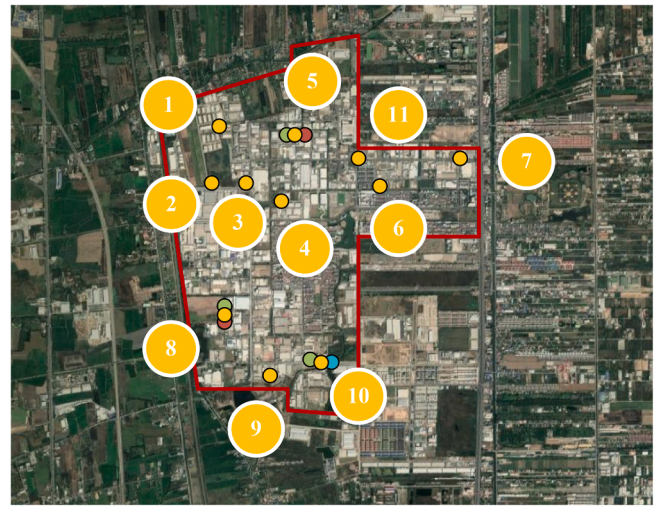


Fig. 8. The location of eleven greenfield towers. (Yellow dots represent eleven greenfield towers with appropriate sites within the industrial estate. Two additional greenfield tower sites at locations 4 and 9 are required.) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3  
Project investment cost (4/5G).

CAPEX		Unit price (each tower)		QTY	SUM
		Total	Grand Total		
1. Engineering					
-site survey	276				
-soil investigation	649				
-report	194	1,119			
2. Tower					
-SS 36 m	15,269				
-foundation	8,284				
-bore pile 0.35 m	11,023				
-SS 36 m	15,269				
-antenna mounting	130	34,706			
3. Equipment location					
-e-stand H2m	1,898				
-AC system	2,200				
-earthing	1,781				
-lighting system	116	5,995			
4. Site preparation	6,579	6,579			
5. Electrical system	16,244	16,244	64,643		
				11	711,073
OPEX	DESCRIPTION		SUM		
1. Maintenance	0.5% of investment	3,555			
2. SA	2.5% of revenue	17,776			
3. Insurance	0.4% of investment	2,844			
4. Rental space	$\$6.5 \times 60 \text{ m}^2 \times 12 \times 11$	51,480			
5. Depreciation	15 years	47,650			
					123,305

\* BTS/BTC/FSR \*\*\$1 = THB30.78

3). Each tower-sharing site supports a maximum load of the devices of the three operators. Therefore, there will be three cases. The F value is 0.2.

Table 4 lists the rental costs obtained from (5) to (8). If there is one

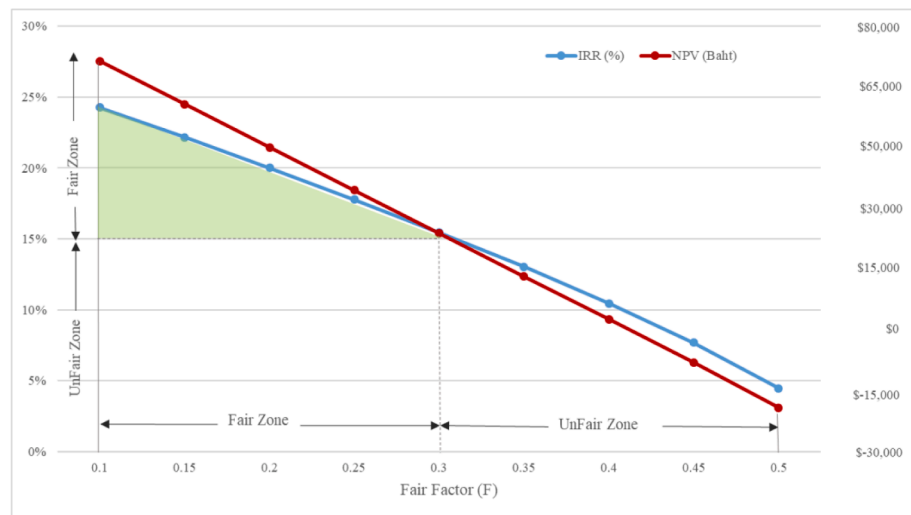


Fig. 9. The relationship among IRR, NPV, and fair factor.

Table 4

The proposed cost-sharing formula per site in Case 2.

Case / No. of Operator (N)	Rentavg (5)	Fair factor (F)	W* (6)	MRent (7)	Total rental (8)
Case 1					
1	1,110	0.2	1	1,110	1,110
Case 2					
2	1,110	0.2	0.8	880	1,760
Case 3					
3	1,110	0.2	0.6	666	1,998

\* weight fair cost-sharing.

operator, the rental cost would be \$1,100, with a total rental income of \$1,100. If there are two operators, the monthly rental cost will decrease to \$880 with a total rental income of \$1,760. Finally, if three operators are, the rental cost will fall to \$666, with a total rental income of \$1,998 per month.

The input values to the second column (Table 5) come from the fifth column values (Table 4). The number of towers (Table 5) comes from the feasibility study and cost modeling focus group discussions. With these values, the monthly income of \$18,536 and a yearly income of \$222,432 can be calculated. Tables 4 and 5 demonstrate the annual expenditure and income. The values from these tables are used to calculate the estimated IRR, payback, and NPV.

Table 6 presents the financial analysis. The recommended IRR should be above 15%. The F value should be less than 0.3. At the F value of 0.3, the estimated payback is six years of fifteen-year project life, and the NPV is \$258,561. The F value of 0.2 is recommended (the default value). The operators do not prefer the value between 0.1 and 0.15 due to a higher rental cost. It would generate a higher profit for the industrial estate. The rental costs at the F value of 0.2 are acceptable (Table 4).

Fig. 9 displays a relationship among the IRR, NPV, and F values. The vertical axis (left-hand side) represents the IRR. The horizontal axis represents the F value. The IRR and F value relationship indicate that if

Table 5

Rental income from the three operators.

No. of operator/tower	Per operator/month	No. of towers	Monthly	Yearly
1	1,110	2	2,220	26,640
2	880	7	12,320	147,840
3	666	2	3,996	47,952
Total		11	18,536	222,432

Table 6

Financial analysis.

Zone	Fair factor (F)	IRR%	Payback (yrs)	NPV
Fair	0.1	24	4.07	718,374
	0.15	22	4.40	603,423
	0.2	20	4.80	488,471
	0.25	18	5.29	373,517
	0.3	15	5.89	258,561
Unfair	0.35	13	6.63	143,604
	0.4	10	7.61	28,644
	0.45	8	8.97	-86,445
	0.5	4	10.96	-207,899

the F increases from 0.1 to 0.5, the IRR decreases from 24% to 4%. Therefore, the preferred IRR is equal to or higher than 15%. The F value should be in the range of 0.1 to 0.3. This is known as a “fair zone” in the horizontal axis. If the F value is higher than 0.3, then the IRR starts to reduce below 15%. This resulted in the “unfair zone.” The vertical axis on the right-hand side represents the NPV in a unit of the USD. Since the relationship between the IRR and NPV is in the same direction, the F and the NPV are also in the same order. When the F value is in a range of 0.3 to 0.5, the NPV will reduce from \$258,561 to \$-207,899. This resulted in an unfair zone. Hence, this project may not be preferred.

The focus group discussions were conducted to assess the acceptance of the cost-sharing model. The results revealed the mean of 4.75 indicated high acceptance (Table 7). The experts made some comments. In the W, the decreasing step function should be taken from others rather than a liner function. The MRent’s price should be the same (\$880) since it benefits the other two operators. Thus, the F value of less than 0.2 would generate more profit but not be fair for the operators.

The findings in Step 3 (Fig. 2) were as follows. The experts had given

Table 7

Findings on the focus group discussions from Table 4.

Item	Description	Mean	Std. Deviation	Std. Error
1	Fair factor (F)	5.00	0.000	0.000
2	Weight fair cost-sharing (W) in (6)	4.63	0.518	0.183
3	Multi-operator rental (MRent) in (7)	4.50	0.535	0.189
4	Total rental per site in (8)	4.50	0.535	0.189
5	Rental income (Table 5)	4.50	0.535	0.189
6	The cost-sharing model	4.75	0.463	0.164
Total		4.65	0.430	0.152

4.83 as the mean acceptance rate of PMNPO (Std. Deviation = 0.389, Std. Error = 0.112). There was a minimal difference in the components, with the range between 4.50 and 4.80. The mean score for the PD is 4.50 (Std. Deviation = 0.527, Std. Error = 0.167). The mean score for the OPT is 4.70 with the Std. Deviation of 0.485 (Std. Error = 0.153).

### The proposed PMNPO

#### An overview of the PMNPO

The PMNPO integrates the theoretical models proposed by Bowarnkitiwong (2013), Insombat (2015), Phengsawat (2014), and Silpanilaman (2017). The key elements are the PD and the OPT (Fig. 10). The PD process contains the planning, design, and cost model components. The starting point of the PMNPO is the planning component. This is followed by the design component and the cost model component. If the target is not satisfied (KPI definition), it cycles back to the planning component until the target is satisfied. Once it is completed, it checks whether it is a permanent or temporary site. If it is a permanent site (case 2), it progresses to the regulatory bodies. If it is a temporary site (case 1), the regulatory requirement is not required. However, it is necessary to obtain permission from the landlord. The implementation component lies beyond the scope of this work. This is because the implementation component requires civil and electrical engineering works. Two major components under the OPT are the NPM and the PT. The direction begins with the NPM and ends with the PT. If the target is optimized, the process is checked PT whether it is satisfied or not. If it is not satisfied or a request to upgrade, it cycles back to the PD. Otherwise, the process is

stopped. The PMNPO can represent in the form of the pseudo-code (Appendix A).

Additionally, massive or large multiple-input multiple-output (MIMO) is an extension of MIMO that expands the “legacy systems” by adding more antennas on the BS. The “massive” number of antennas improves efficiency and throughput. Thus, the Massive MIMO aims to achieve performance improvements underpin the 5G experiences users. Furthermore, the Massive MIMO is within the planning segment under capacity and coverage of the PMNPO (Fig. 10).

### Discussion

#### The fair factor

The introduced cost-sharing model is new and presents a completely practical approach to the MNPO. However, as a technique in its early stages, there is room for improvement. The W values were 1, 0.8, and 0.6, respectively (Table 4). The different value was found to be 0.2. The idea behind the F value is a decreasing step function. The decreasing step function takes a linear function. Other functions, such as a parabola, can be applied.

The SVM is excluded from the traditional theory (Laiho, Wacker, et al., 2006). The SVM in the planning is according to the views of the experts. Since the budget for the network extension is limited, the site is the top priority the MNP engineer considers. Considering a case where the customers demand more capacity in the co-tower area, the engineer will need to evaluate whether the site is appropriated or not. If the co-towering cost is too expensive, the operator will not provide the

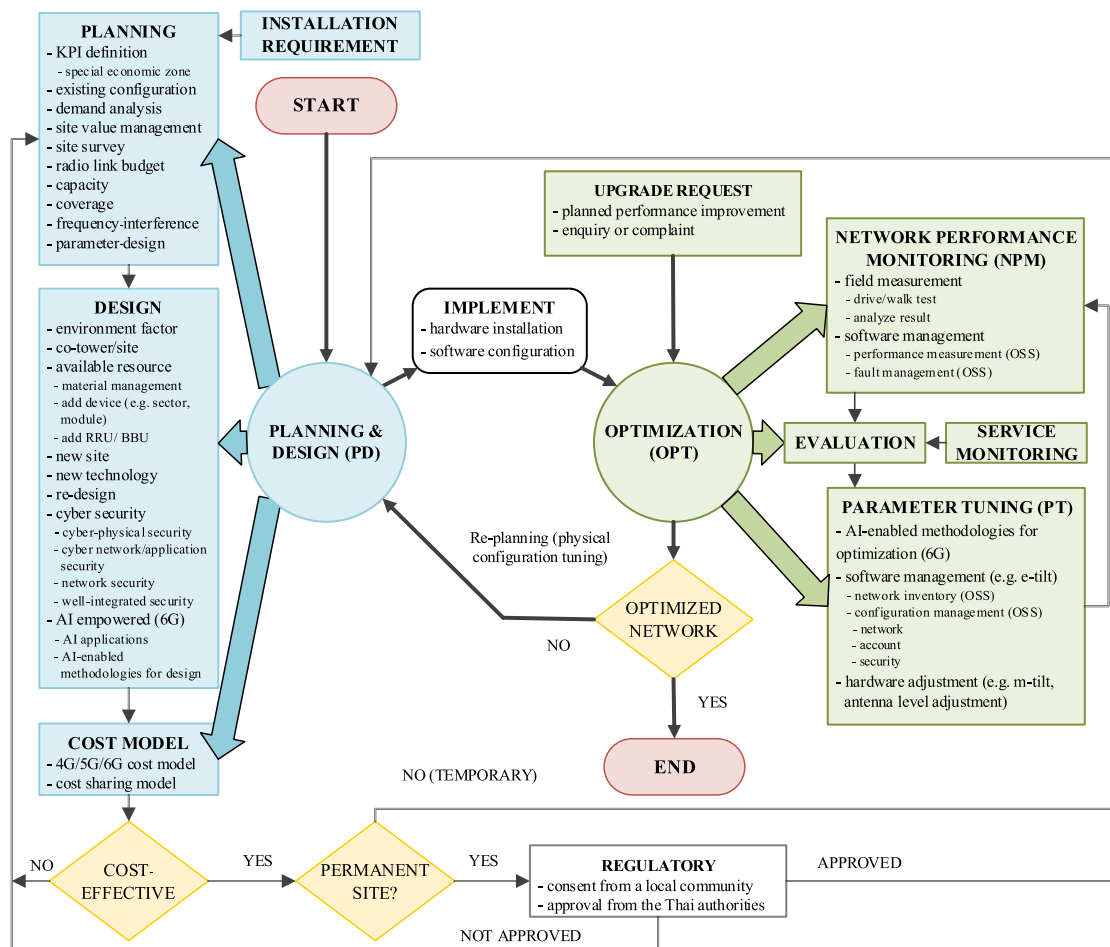


Fig. 10. The proposed diagram of the PMNPO.

adequate capacity required by the customers. This resulted in the degraded QoS. Therefore, the F value is essential to enable the co-towering solution in smart cities.

#### *The IRR, payback, and NPV*

The total yearly rental income is \$222,432 based on two towers for the three operators (Table 5). The IRR, payback, and NPV will be improved if the operators per tower increase. For example, the total yearly rental income will be \$236,712 if the number of operators per tower increases to seven and the two operators per single tower reduces to two (Table 8).

The difference in the total yearly rental income is \$14,280. The calculated values of the NPV, IRR, and payback are \$576,896, 21.7%, and 4.5 years. This indicated a fair value for both owner and tenants of a tower. If the owner prefers an original profit (IRR of 20%), the increased profit can deduct the rental income in (5)  $Rent_{avg}$ . This will result in a fairer rental fee and a lower overall rental fee.

#### *The PMNPO*

The existing models appear to have been formulated either on a theoretical basis or a value proposition basis. There is no single model that integrated both bases, especially in terms of a practical basis. The PMNPO is built upon the previously published works (Chimmanee & Jantavongso, 2016; Knoll, 2014; Lombardo, 2019; Nikolicj & Janevski, 2015; Oughton & Frias, 2018; Smail & Weijia, 2017). In addition, the PMNPO includes the workable cost model, which provides the network service's economic and financial justification.

The key components of the PMNPO are the KPI definition, NPM, PT, and optimized network. These components were identified in (Chimmanee & Jantavongso, 2016; Mishra, 2018). The PMNPO synthesizes the works on the NPO algorithm (Ceselli et al., 2017; El-Beaino et al., 2015; González et al., 2018; Pérez-Romero et al., 2016; Sandoval et al., 2016; Tsoulos et al., 2017). Moreover, the PMNPO integrates the existing works on 5G in smart cities (Boukerche et al., 2019; Raissi et al., 2019; Rusti et al., 2018; Rusti, Stefanescu, Iordache, Ghenta, Brezeanu, et al., 2019; Rusti, Stefanescu, Iordache, Ghenta, Patachia, et al., 2019). The materials from these studies can be learned and contributed to the PMNPO.

The security of 5/6G has been prioritized in recent research studies (Ahmad et al., 2019; Fang et al., 2017; Hasnat et al., 2019; Huang et al., 2019; Tang et al., 2020). The network must secure the services, components, and users (Ahmad et al., 2019). Therefore, integrated network security is vital for 6G. The physical and network layer security formulate a well-integrated 6G security solution (Huang et al., 2019). The cybersecurity function is included in the design and PT process of the PMNPO. This is following the work by (Ahmad et al., 2019). The security challenges must be cautious from the early design stage. However, the implementation process is excluded from this paper. OSS has been included in the PMNPO. The operator's back office commonly uses OSS (Bruce et al., 2005; Goncalves et al., 2007; Mazhelis et al., 2007). Configuration management is used to reconfigure devices remotely. Therefore, the cybersecurity component has been included.

Service quality monitoring stores details about resource and customer services. It adds value to cover the AI knowledge and enhance

capability and accuracy. For instance, the marketing department can monitor the service quality via the service monitor application. In contrast, the engineering team can monitor the quality of service from the network layer-based OSS. A threshold alarm mechanism is needed. The service monitoring component has been added to the PMNPO.

The PMNPO is not focused on the front office (Bruce et al., 2005). The 6G service will surpass the mobile internet. The ubiquitous AI services will need to be supported by the end devices. AI will continue to have a critical role in the design and optimization of 6G. Thus, the AI applications and AI-enabled components for 6G are included in the PMNPO.

At the time of writing, the industrial estate has implemented the 5G network following the proposed pseudo-code of the PMNPO (management function). However, it required changes in hardware devices on the greenfield towers. One possible explanation was due to the lower user numbers. The solution was to add more small cells to cope with the demands. The authors believe that the proposed pseudo-code can apply to both network generations.

#### *The co-infrastructure*

The co-towering and cost-sharing models are essential for the SSCs in Thailand. The SSCs are declared as special economic zones. The KPI definitions had been defined: a minimum of 50% coverage within a year, and at least 50% of the population within four years (NBTC, 2019). The experts believed that the towers will still be needed even though small cells will be popular for 5/6G networks.

Many MN towers are in crowded community areas. For instance, three operators must compete to set up their towers within the same site. Accordingly, 5G will need to be installed as the microcells and picocells. The future network will still require a large amount of additional investment. The NBTC is now considering the infrastructure-sharing network (NBTC, 2018). Despite this, the Thai government has not established a clear policy on this issue.

#### *Policy recommendations*

As mentioned, mobile networks are the backbones of smart cities. The smart city initiative is expected to cover one hundred Thai cities by 2023. The Thai government is keen on developing the digital economy and society, and digital infrastructure. The Thai government has emphasized providing hard infrastructure and conducted a smart city pilot project. As a result, the nation-wide high-capacity digital infrastructure has been initiated. A policy recommendation that reflects the changing digital landscape while minimizing costs and barriers to mobile network deployment will help deliver the community's outcomes.

Two recommendations of policy action are related to regulation and network investment. First, the Thai government is to support the sharing of mobile network infrastructure (infrastructure sharing) that will help to expand the network more efficiently and faster. It is envisaged that appropriate infrastructure-sharing is the key to minimizing the 5G/6G network rollout cost. The Thai government has not established a clear policy on this issue. There is also a need for the Thai government to take a proactive stance. The NBTC needs to confirm the site priority zone issue for smart cities.

Second, the proposed cost-sharing model for mobile networks comprised of CAPEX, OPEX, feasibility study, and site value management (mobile network operators) is the key to minimizing the 5G/6G network rollout cost. Therefore, the government should consider the cost-sharing model.

#### **Conclusion**

The PMNPO integrates the three perspectives of academic, practical, and business. The practical approach must be included in the traditional theories or technical books from the theoretical perspective. Some

**Table 8**  
Adjusted rental income (revenue).

No. of operators/ tower	Per operator/ month	No. of towers	Monthly	Yearly
1	1,110	2	2,220	26,640
2	880	2	3,520	42,240
3	666	7	13,986	167,832
Total		11	19,726	236,712



practical approaches may have been overlooked from a practical standpoint - for instance, the cost-sharing model and the SVM. From the business perspective, the co-towering solution's fair rental price remains a problem for Thai operators. While many attempts to offer the bidding for the co-sharing project, it was unsuccessful in coming up with a reasonable rental fee. Some operators were decided to rent only at specific points. This has resulted in problems of coverage and capacity.

This study proposed the cost-sharing model for co-tower solutions with the fair factor that's workable of SSCs. The operators require the total picture. The existing processes mainly were based on 4G networks. Therefore, there is a need for future features to be included. The PMNPO is a novelty of the complete picture integrated with the traditional theories, technical books, actual practices, and the 5/6G features. As such, the PMNPO presents a significant shift by integrating those three mentioned views. This paper also provides a forward-looking research framework for 6G.

There is also a need for the Thai government to take a proactive stance. But, unfortunately, while it may influence the Thai government, telecommunication's policy lies beyond the authors' capability.

In summary, this study developed and evaluated the infrastructure cost-sharing within Thailand's smart and sustainable city. It has not only proffered the PMNPO but has also presented evidence that supports the propositions. Thus, there is positive evidence that the PMNPO is a generic practical framework for a smart city model suitable for Thailand. However, further research may still be required for the infrastructure-sharing cost of small and microcells.

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#### CRedit authorship contribution statement

**Krishna Chimmanee:** Conceptualization, Methodology, Investigation, Software, Data curation. **Suttisak Jantavongso:** Writing - review & editing, Formal analysis, Visualization.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Appendix A

##### A. Pseudo-code of the PMNPO (management function)

The management functions (procedures) are presented in the pseudo-code form.

##### B. Main procedure

**Input:** Request (installation, re-planning)

**Output:** KPI satisfy, cost-effective

- (1) **Start**
- (2) Step 1. **If** (there is Request) then
- (3) {**Select case:** Request}
- (4) {**case:** Request = Installation}
- (5) {**case:** Request = Improvement}
- (6) { **Goto** Line 13}
- (7) {**case:** Request = Complaint}
- (8) { **Goto** Line 13}

- (9) {**End select**}
- (10) **End if**
- (11) Step 2. **Do Loop**
- (12) Step 3. *Call* Planning procedure
- (13) Step 4. *Call* Design/Cost model procedure
- (14) Step 5. *Call* Regulator procedure
- (15) Step 6. **Until** (Regulator is approved or none)
- (16) Step 7. Implementation
- (17) Step 8. *Call* Optimization procedure
- (18) Step 9. **If** (Optimization is Able)
- (19) {**Goto** Line 23}
- (20) **Else**
- (21) {**Goto** Line 12}
- (22) **End if**
- (23) **Stop**

The implementation component is excluded because it is an extraneous variable. The above pseudo-code is the main procedure and function, which calls other procedures or functions.

##### C. Planning procedure

**Input:** Installation requirement

**Output:** Planning information

- (1) **Start**
- (2) Step 1. KPI Definition
- (3) Step 2. Existing configuration
- (4) Step 3. Demand analysis
- (5) Step 4. Site value management
- (6) Step 5. Site survey
- (7) Step 6. Radio link budget
- (8) Step 7. Capacity evaluation
- (9) Step 8. Coverage analysis
- (10) Step 9. Frequency-interference
- (11) Step 10. Parameter-design
- (12) Step 11. **Return** Planning information
- (13) **Stop**

The KPI definition in *Step 1* is divided into the QoS and the special zone. The defaulted QoS is according to the NBTC. For Thailand, the RTT of 4G should be less than 150ms. The download speed should be above 2.5Mbps, and the upload speed should be more than 500Kbps. The HTTP success ratio should be at 90%. However, the QoS for 5G has not been issued by the NBTC. The spectrum licensee in the 260MHz must cover a minimum of 50% in the special economic promotion zones within a year from the license grant date and at least 50% of the population in each zone within four years. Therefore, the estimated traffic demand in *Step 3* should incorporate the current and future needs at peak hours (Rahnema & Dryjanski, 2017).

##### D. Design/cost model procedure

**Input:** Planning information

**Output:** Design method & information

- (1) **Start**
- (2) Step 1. Environment factor
- (3) Step 2. Co-tower/site
- (4) Step 3. **Do Loop**
- (5) Step 4. Material management
- (6) Step 5. **If** (there is existing resource) then
- (7) {**Select case:** *method*}
- (8) {**case:** *method* = Add device}
- (9) { **Goto** Line 23 with *method*}
- (10) {**case:** *method* = RRU/BBU}
- (11) { **Goto** Line 23 with *method*}
- (12) {**case:** *method* = unsatisfied}
- (13) { **Goto** Line 15}
- (14) {**End select**}

(15) Step 6. **Else**  
 (16) {**Select case:** *method*}  
 (17) {**case:** *method* = New site}  
 (18) { **Goto** Line 23 with *method*, temporary or permanent}  
 (19) {**case:** *method* = New technology}  
 (20) { **Goto** Line 23 with *method*, temporary or permanent}  
 (21) {**case:** *method* = Re-design}  
 (22) { **Goto** Line 23 with *method*, temporary or permanent}  
 (23) {**End select**}  
 (24) **End if**  
 (25) Step 7. **Until** (Cost-effective {4G/5G/6G cost, cost-sharing} is able)  
 (26) Step 8. Cyber security  
 (27) Step 9. Cyber-physical security  
 (28) Step 10. Cyber network/application security  
 (29) Step 11. Well-integrated multi-level security  
 (30) Step 12. AI-empowered  
 (31) Step 13. AI-application  
 (32) Step 14. AI-enabled mythologies for design  
 (33) Step 15. **Return** *Design* = {*method*}, {temporary or permanent} & information  
 (34) **Stop**

Steps 3-8 are the design procedure included in the cost model. This cost model can accommodate 4G towards 6G networks. The co-towering is included. While the cost model for 4G/5G may have been reported (Knoll, 2014; Nikolikj & Janevski, 2015; Oughton & Frias, 2018), the cost model for 6G is a work in progress. Steps 9-15 focus on the 5G/6G network. Moreover, Step 10 deals with the CPS that revolved around the human factors. The security solutions used in 4G are to be evolved. The new security aspects of 5G must be considered (Fang et al., 2017). The security issues in Steps 9-12 are the 6G critical issues. Some physical layer security techniques intended for 5G can be extended. A sound security management mechanism is vital (Huang et al., 2019). 6G needs to support AI-enabled applications at edge devices in Step 13. Thus, flexible platforms for developing advanced computation technologies and communication are required in 6G (Letaief et al., 2019). The AI design in Step 14 refers to the mixture of AI and edge computing. It enhances the experience quality and reduces the cost. Moreover, the AI application is a problem to the 5G optimization. The AI-driven approach should be taken in 6G. Hence, 6G provides a significant increase in QoS (Huang et al., 2019).

#### E. Regulator procedure

**Input:** Design information

**Output:** Regulator

(1) **Start**  
 (2) Step 1. **If** (*Design* is {new site} and {permanent})  
 (3) {**Goto** Line 7}  
 (4) Step 2. **Else**  
 (5) {**Goto** Line 9 with none}  
 (6) **End if**  
 (7) Step 3. Consent from local community  
 (8) Step 4. Approval from Thai authorities  
 (9) Step 5. **Return** regulator = *approved/not approved/none*  
 (10) **Stop**

#### F. Optimization (OPT) procedure

**Input:** Upgrade request or implement

**Output:** Optimization

(1) **Start**  
 (2) Step 1. *Call* Network Performance Monitoring  
 (3) Step 2. *Call* Service Monitoring  
 (4) Step 3. *Call* Evaluation  
 (5) Step 4. **If** (*QoS* is *Able*)

(6) {**Goto** Line 16 with *Able*}  
 (7) **Else**  
 (8) {**Goto** Line 10}  
 (9) **End if**  
 (10) Step 5. *Call* Parameter Tuning  
 (11) Step 6. **If** (*Parameter Tuning* is *Able*)  
 (12) {**Goto** Line 16 with *Able*}  
 (13) **Else**  
 (14) {**Goto** Line 16 with *Unable*}  
 (15) **End if**  
 (16) Step 7. **Return** Optimization = {*Able or Unable*} & information  
 (17) **Stop**

A third party makes the traditional service monitoring, and it will not be further mentioned.

#### Network performance monitoring procedure

**Input:** Gathering of network monitoring information

**Output:** Network monitoring result

(1) **Start**  
 (2) Step 1. Field measurement  
 (3) Step 2. Walk or drive test  
 (4) Step 3. Analyze result  
 (5) Step 4. Software management (OSS)  
 (6) Step 5. Performance measurement (OSS)  
 (7) Step 6. Fault management (OSS)  
 (8) Step 7. **Return** Network monitoring result  
 (9) **Stop**

Steps 1-3 must be implemented. These steps are not the same as Steps 4-6. Steps 1-2 consist of a walk or drive test with result analysis. Steps 4-6 are software-based in the OSS. They are automatically executed. Step 5 monitors the traffic flow and the ability of the devices to support that traffics. Step 6 alarms the network for diagnosing faults.

#### Evaluation procedure

**Input:** Gathering of result from the network and service monitoring

**Output:** Evaluation result and information

(1) **Start**  
 (2) Step 1. Network monitoring result  
 (3) Step 2. Service monitoring result  
 (4) Step 3. **If** (*QoS of network monitoring result* is *Able*) and (*QoS of service monitoring result* is *Able*)  
 (5) {**Goto** Line 9 with *Able*}  
 (6) **Else**  
 (7) {**Goto** Line 9 with *Unable*}  
 (8) **End if**  
 (9) Step 4. **Return** Evaluation = {*Able or Unable*} & information  
 (10) **Stop**

Step 2 monitors the service quality. AI generates the added value to enhance AI knowledge. The service monitoring can be programmed or generated by a software house. Events can be processed in the application software to conduct the impact analysis for the services in Step 3. Service quality management, fault management, and performance management can be graphically presented.

#### Parameter tuning procedure

**Input:** Evaluation information

**Output:** Parameter tuning result & information

(1) **Start**  
 (2) Step 1. AI-enabled methodologies for optimization  
 (3) Step 2. Software management  
 (4) Step 3. Network inventory (OSS)  
 (5) Step 4. Configuration management (OSS)  
 (6) Step 5. Network configuration (OSS)

(7) Step 6. Account configuration (OSS)  
 (8) Step 7. Security configuration (OSS)  
 (9) Step 8. Hardware adjustment  
 (10) Step 9. Call Network Performance Monitoring  
 (11) Step 10. Call Service Monitoring  
 (12) Step 11. Call Evaluation  
 (13) Step 12. If (QoS is Able)  
 (14) {Goto Line 18 with Able}  
 (15) Else  
 (16) {Goto Line 18 with Unable}  
 (17) End if  
 (18) Step 13. Return Parameter Tuning = {Able or Unable} & information  
 (19) Stop

Step 1 is needed because the 6G network is complexed. The traditional optimization methods are not sufficient. AI provides closed-loop optimization and automation (Letaief et al., 2019). Furthermore, AI can facilitate end-to-end optimization in the physical layer. This system is self-learning and optimization. A deep neural network can train the receivers, transmitters, and channels (Fang et al., 2017; Letaief et al., 2019). Step 2 consists of the network inventory and the configuration management belonged to OSS. Step 3 contains the as-designed model with the customer-facing data. Step 4 eliminates the risk related to the configuration of devices. Step 5 includes the changes to enhance the network performance. Step 6 provides the statistics of the service usages. It is used for billing purposes. Step 7 confirms customers have access to only resources they are entitled to use. Finally, Step 8 is needed in a situation where the software management cannot reconfigure remotely.

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