IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

A Techno-economic Analysis of Simulation-based 5G Femtocell Implementation at ITERA

To cite this article: U A Ramadhani *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **258** 012033

View the article online for updates and enhancements.

This content was downloaded from IP address 115.200.250.181 on 08/10/2019 at 12:06

A Techno-economic Analysis of Simulation-based 5G Femtocell Implementation at ITERA

U A Ramadhani [1], W Febrianti [2], and H Najemi [1]

[1] Department of Production and Industrial Technology, Institut Teknologi Sumatera, Indonesia
[2] Department of Science, Institut Teknologi Sumatera, Indonesia

Abstract. In line with the rapid evolution of cellular communication technology, there is a high demand for data traffic required by the mobile users. The 5G technology is considered as the solution that can provide data rates up to 10 GB/s to meet such a high data traffic demand with millimeter wave utilization. Indonesia, with its large amount of mobile users, and Sumatera Institute of Technology (ITERA), as an accelerator of technology enhancement in western Indonesia, necessarily need good preparation in the implementation of commercial 5G technology. In this work, we investigate suitable network dimension scenarios to achieve the targeted data rates according to the 5G standards. By using the projected number of mobile communication users in ITERA and daily data traffic demand, several network dimension scenarios and femtocell network parameters are simulated to attain mobile users' data rates. The network dimension scenarios are then analyzed in terms of deployment cost. By analyzing the network dimensions from a techno-economic perspective, the most effective and efficient scenario is selected. The results of this research can bring an insight in network planning when deploying 5G mobile communications infrastructure at ITERA.

Keywords: *5G, millimeter wave, femtocell, data rates, deployment cost*

I. Introduction

In the last few decades, the development of telecommunications technology has evolved significantly, from being based solely on certain mediums such as copper cable, into flexible technology to operate in various forms of applications and followed by ever increasing capacity. 4G technology which began commercially since 2013 in Indonesia will soon be replaced with 5G technology that is already on the doorstep.

Institut Teknologi Sumatera (ITERA) as a technology-based campus should be agile in responding to the entry of this 5G technology. In accordance with the vision and mission to realize the smart campus, a study on the implementation of 5G technology in the ITERA education area is needed. This study aims to identify the 5G network scenario that is able to meet the demand for capacity and wide area coverage.

In this paper, we performed a techno-economic analysis of 5G femtocell network deployment at ITERA. This paper consists of five sections. The characteristics of 5G technology will be described in Section II. Section III covers the simulation model to evaluate the performance of 5G femtocell

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

network. Section IV contains the simulation results and discussion of the cost analysis of 5G femtocell network deployment. Finally, the conclusion about this work will be presented in Section V.

2. Characteristics of 5G Networks

The standardization of 5G networks is in ongoing process. However, ITU-T [1] has specified characteristics that must exist in a 5G network. ITU-R has been studying the 5G standards by means of International Mobile Telecommunication with the target date set for 2020 (IMT-2020) [2].

2.1 5G Requirements

The key features of 5G networks has been developed by the ITU Radio Communication Sector as the followings:

Data rate

The 5G technology is targeted to be able to provide a minimum data rate of 1 Gb/s [3]. Moreover in [4], ITU has stated that 5G network could achieve a peak data rate of 10 Gb/s per connection. To guarantee the user's level of Quality of Experience (QoE) and Quality of Service (QoS), a user should receive 50 MB/s, even at cell edges and dense areas.

Mobility

Since the access of communication is more flexible, users not only connect to the network in low mobility but a user also demand to have a good connection when in a very high speed vehicle. The 5G network is expected to provide the acceptable data rate at speed of 500 km/hr [4].

Latency

The 5G network should bring less latency compared to the current network. The latency requirement will be in the range of 1-5 ms [5].

Connection Density

It is believed that the architecture of 5G network will be more complex which allows not only voice and data communications but also Device to Device (D2D) communications, wireless sensors, Internet of Things (IoT), and wearable computing. The application of these type of communications will be broad, for example from health service, autonomous vehicles, and smart city. The 5G network is expected to integrate the connected devices up to 100 times that of the current mobile network [4].

Multiple Radio Access Technologies (RATs)

To enhance from 4G to 5G network, the 5G technology should not completely replace the current wireless network. The future technology should be able to integrate the existing mobile networks [4].

Energy and cost efficiency

The 5G network should achieve the efficiency energy usage by a factor of 1000 compared to existing wireless networks [4]. Furthermore, the 5G technology should have a flexibility to be

IOP Conf. Series: Earth and Environmental Science **258** (2019) 012033 doi:10.1088/1755-1315/258/1/012033

deployed at low Average Revenue per User (ARPU) area, hence it will cost low CAPEX and OPEX [2].

2.2 5G Femtocell
Ultra-dense network in the future will require extreme demand of data rates and mainly generated from indoors, which can only be met by utilizing multiple base stations with small radius. Femtocell is known as an efficient solution in providing wireless communication services indoors. With a base station size that is small enough or called access points, with radius of 10 to 50 m [6], financing for the femtocell is much cheaper than building a macrocell network.

Femtocell access methods relate to environmental conditions and business models. At Closed Subscriber Group (CSG) only certain users who have been registered can access the service, while in the femtocell Open Subscriber Group (OSG) can be accessed by all users. In hybrid access mode, some femtocells can serve unregistered users. This femtocell access mode will affect the determination of the number of femtocells for an area coverage.

2.3 Beamforming
In order to fulfil the requirements of 5G technology, the networks should be able to provide a user with higher data rates and increase the capacity of the systems. Beamforming is a technique that can answer those challenges by steering the signal transmission from an array of N antennas to one or multiple intended users. Furthermore, the beamforming also aims to reduce interference from non-intended users [7]. Beamforming is also related to power consumption of the system. However, it is a difficult task to achieve a system with maximum signal power and power efficiency while have minimum interference leakage.

Massive Multi-Input-Multi-Output (MIMO) can be considered as a form of beamforming. With large number of antennas both in the base station and the user terminal. The base station applies distinct precoding for the data stream of each and effectively collect the Channel State Information (CSI) between each antenna and user terminal. Relative amplitude and phase shifts are applied to steer signal beam to the intended user and in the same time minimize interference from signals of other users by destructively canceling each other. Several signal processing methods that enables Massive MIMO are Maximum Ratio (MR), Zero Forcing (ZR), and Minimum Mean Square Error (MMSE).

2.4 Deployment Cost of 5G Femtocell Network
With a smaller service distance from macro cells, the number of femtocells needed for an area coverage can be very large so that the evaluation of the influence of the economic side of the Radio Access Network (RAN) becomes very important. The costs required for building femtocell access points consist of Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). Capex includes all the expenses related to the investment in the network infrastructure, such as base station equipment, site installation, site buildout, and radio network controller equipment. Opex relates to the cost of operation and maintaining the network infrastructures, for examples electric power, operation and maintenance (O&M), and site lease.

The techno-economic aspect of 5G network deployment can be analyzed by considering two scenarios [8]. First, it is assumed that new RAT is deployed with new antenna system and radio equipment without affecting the fiber backhaul already installed. Rather than replace the RAT, in the second scenario the previous RAT is enhanced by adding new carriers and radio equipment to the existing RAT. This scenario is preferable for mobile operators that already run their business in the market.

The CAPEX cost of 5G network is calculated based on the cost model proposed by [9]. For MIMO equipment, the CAPEX is determined based on Eq. 1.

$$C_{CAPEX} = B(C_{ff} + C_{EPC})(M_s + M_d)\frac{r(1+r)^n}{(1+r)^n-1} \quad (1)$$

C_{CAPEX} is the total CAPEX, B is the number of base stations, C_{ff} and, C_{EPC} are the cost of RAN 5G femtocell and the cost for Evolved Packet Core (EPC), respectively. M_s and M_d represent the number of antennas for source and destination of MIMO configuration. r is the periodic interest rate and n represents the length of installment plan in years.

The cost of OPEX for 5G network which depends on expense for running the system is determined as follows:

$$C_{OPEX} = (M_s + M_d)\left[B(c_{run} + c_{bh})\left(C_{ff} + C_{EPC}\right)\right)\frac{r(1+r)^n}{(1+r)^n-1} + Bc_{st} + f_{BW}BW] \quad (2)$$

where c_{run} is the cost of power consumption, c_{bh} is the backhaul cost. c_{st} represents the cost for site operation and support. f_{BW} is the cost of bandwidth leasing.

3. Simulation Model

The method used in the study uses a quantitative approach based on measurements from technical and economic aspects. To carry out the research thoroughly, the steps to be taken are the determination of the problem formulation which is to obtain the suitable 5G femtocell network scenarios to be implemented in ITERA. Then followed by a literature study to choose the right solution for solving the problem. The femtocell network will be built at the computer simulation level based on the initial data of traffic demand in the area, and then data collection in the form of data rates obtained by the user can be done.

3.1 Network Dimension

In order to build the network system in the simulation level, it is necessary to have the estimated traffic demand in area of interest, i.e. indoors of ITERA's buildings.

The scenario deployment depends on both coverage and traffic demand. Based on the master plan of ITERA development, by the year of 2037 it is expected there will be 37360 number of users and 401023 m^2.

According to Ericsson's mobility report [10], average traffic demand per month per user is 10 GB with peak traffic of 8 hours per day. Hence, daily traffic demand is approximated as much 3,46 Mbps per user. We used indoor spectral efficiency of 6.6 bps/Hz and 20 MHz of spectrum for a femtocell base station [8].

In this project, we considered the service range of femtocell base station is 25 m, with the large area of each base station taking a hexagonal shape.

From these data, in order to design the dimension of the network we should meet both coverage and traffic demand. We found that at least 205 base station is needed to fulfill the traffic and coverage demand for wireless communication around ITERA by the year of 2037. The femtocell network was simulated with 183 number of users per cell and the user's location was uniformly distributed.

3.2 Network Parameter

The simulation of a 5G femtocell network in Matlab used the system parameters summarized in Table 1.

Table 1. Network Parameter

Description	Value
System bandwidth (MHz)	20
Carrier frequency (GHz)	32
Femtocell transmit power (dBm)	40
Femtocell Base station radius (m)	25
Femtocell Base station height (m)	1.5
Gain (dB)	5
Noise floor (dBm)	-174

3.3 Pathloss Model

From the system parameters in Table 1, the received power in the user terminal can be computed using a link budget calculation as:

$$P_r = P_t + Gain - Cable\ loss - Pathloss - Interference\ margin \quad (3)$$

where P_r is received power, P_t is transmitted power, and $Pathloss$ is the attenuation according to Okumura-Hatta model for the urban area. Having the received power of the user terminal, ratio of signal to interference and noise (SINR) can be obtained as:

$$SINR = P_r - Interference - noise\ floor \quad (4)$$

Interference of a user m from other users j_{th} is calculated by:

$$\Gamma_{m,j} = \sum_{m \neq j_{th}} P_t g_{j_{th}} \quad (5)$$

Then, a user's instantaneous data rate is calculated as the following:

$$datarate = bandwidth\ x\ log_2(1 + SINR) \quad (6)$$

3.4 Beamforming Technique

We applied a simplified MRC beamforming technique proposed by B. Ozbek and U. Bayrak [11] The beamforming vector is obtained by:

$$\boldsymbol{w_k} = \frac{\boldsymbol{h_k}}{||\boldsymbol{h_k}||} \tag{7}$$

Where $\mathbf{h_k}$ is the channel coefficient following Rayleigh channel between the femtocell base station and a user terminal k_{th}. Then the gain belonging to an intended user terminal calculated by:

$$G_{k,k} = |\boldsymbol{h_k w_k}|^2 \tag{8}$$

In the simulation, the beamforming involved 3 different scenarios of MIMO configuration which are MIMO 4X4, MIMO 8X8, and MIMO 16X16.

4. Result and Discussion

4.1 Simulation Result

The result from the simulation of femtocell network with different MIMO scenario is represented in terms of data rates as shown in Figure 1. To achieve the standard of 5G network characteristic, the user should attain at least 1 Gbps [12]. With the configuration of MIMO 16X16, all the users are able to achieve at least 1 Gbps. By utilizing MIMO 8X8, 90% of the users achieve the target data rate, while in MIMO 4X4 configuration, only 11% of the users were able to obtain 1 Gbps data rate.

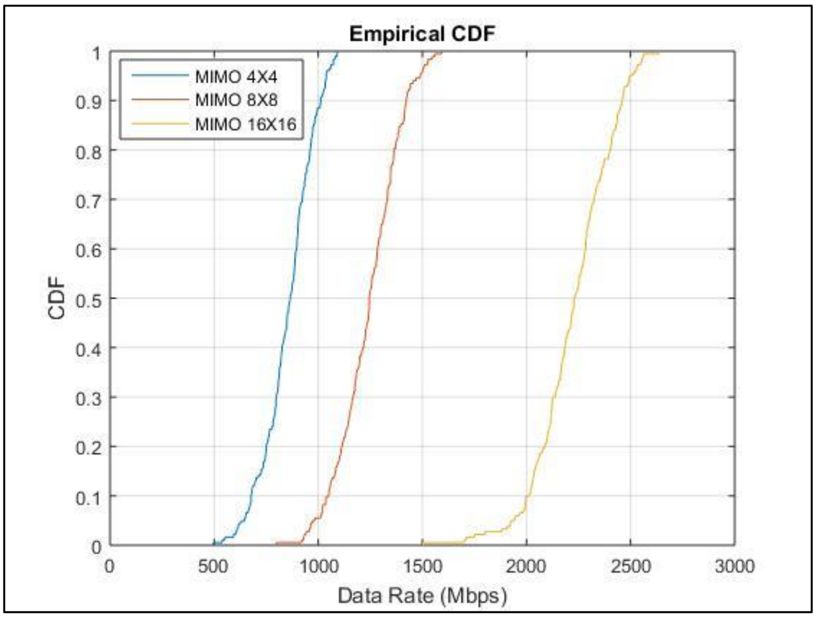

Figure 1. CDF of User's Data Rate

With MIMO 4X4 configuration, the system operates with least reliability than the other MIMO configuration. The users may experience error packet or buffering during streaming a video. By using MIMO 8X8 in network, the cumulative distribution of user's data rate as one of QoS (Quality of

Service) parameter increases as more streams provided during the network operation which then results in the rise of beamforming gain. The network is able to guarantee all users to obtain at least 1 Gbps as the expectation of 5G network characteristic with MIMO 16X16 configuration, and this configuration outperformed other MIMO configurations simulated in this project.

4.2 Cost Analysis

In this subsection, we assessed the deployment cost of 5G network based on the configuration simulated in this project. The CAPEX and OPEX cost for each MIMO configuration were calculated by using the key cost drivers and values mentioned in the study of C. Bouras, S. Kokkalis, A. Kollia, and A. Papazois [9]. The network deployment cost input is shown in Table 2.

Table 2. Network Deployment Cost Input [11]

Parameter	Item	Cost (€)
C_{ff}	Capital cost for single femtocell	1000
C_{EPC}	Core network capital cost	110
c_{run}	Running cost	892.5
c_{bh}	Backhaul cost	4800
f_{BW}	Bandwidth leasing	1170
c_{st}	Operating cost	3100

The CAPEX and OPEX cost was calculated with 10 years of duration of installment and 6% of periodic interest rate [9]. Table 3 shows the CAPEX and OPEX cost for deploying 205 5G femtocell base stations with MIMO 4X4, MIMO 8X8, and MIMO 16X16. As the number elements of arrays antenna increases, the deployment cost increases since the CAPEX and OPEX calculation (Eq. 1 and Eq. 2) depends on the number of elements in MIMO antennas. The total cost of deploying 5G femtocell network by using MIMO 4X4 is the least among other MIMO configuration, with CAPEX and OPEX cost are € 247,334.03 and € 6,446,002.5, respectively. The total cost for deploying MIMO 8X8 5G femtocell network double the total cost of MIMO 4X4 deployment, with CAPEX cost is € 494,668.06 and OPEX cost is € 12,892,045. In MIMO 16X16, the total cost to deploy 5G femtocell network is 26,773,426 and the highest compared to MIMO 4X4 and MIMO 8X8 configuration.

Table 3. Capex and Opex Cost

	Antenna Configuration		
	MIMO 4X4	MIMO 8X8	MIMO16X16
CAPEX (€)	247,334.03	494,668.06	989,336.12
OPEX (€)	6,446,002.5	12,892,045	25,784,090
Total Cost	6,693,356.53	13,386,713.06	26,773,426

Given the performance comparison of 5G femtocell network with different MIMO configuration as depicted in Figure 1 and the cost calculation to deploy those 5G femtocell network scenarios in Table 3, we observe that there is a trade-off between the cost the mobile operator needs to expense and the data rates achieved by the users which is relate to the QoS and user's satisfaction level. With least CAPEX and OPEX cost in MIMO 4X4, there is only 10% of users obtain the acceptable data rate for 5G standard, i.e. 1 Gbps. In MIMO 8X8 configuration, more than 90% of users are able to achieve data rate of 1 Gbps with deployment cost almost reach € 14 millions. By using MIMO 16X16, the mobile operator is able to provide all users with at least 1 Gbps data rate with total cost more than € 25 millions.

5. Conclusion

The 5G technology has been predicted to be able to provide a break-through achievement in telecommunication services. ITERA, as an technology-based higher education institution should prepare to implement the 5G tehcnology network. In this study, we performed a techno-economic assessment of deploying 5G femtocell network at ITERA with different scenarios of MIMO configuration, i.e. MIMO 4X4, MIMO 8x8, and MIMO 16X16. These femtocell network configuration were simulated to evaluate the network performance in terms of data rate. The cost analysis is conducted by considering CAPEX and OPEX expenses of deploying different MIMO configuration in 5G femtocell network. The simulation result shows that in a higher number of antenna elements in the MIMO scenarios, the more users are able to achieve 1 Gbps data rate as the minimum acceptable data rate for 5G characteristic. By using MIMO 16X16, the network can provide all users with minimum 1 Gbps data rate. The number of users who can obtain the same data rate requirement in MIMO 8X8 is 90%, while in MIMO 4X4 only 11% of users. This result is in accordance with the sense that as the number of antenna elements in MIMO configuration increases, there will be increment in beamforming gain, which then results in a higher SINR.

However, the behaviour of network performance in terms of data rate is inversely proportional when it comes to economic assessment to deploy the different 5G network scenarios. In a higher number of antenna elements, the mobile operator needs to expense more cost to build the network. The total cost which include CAPEX and OPEX cost to deploy MIMO 16X16 is more than € 25 millions for ten years installment and the highest among other two scenarios. While for MIMO 8X8 and MIMO 4X4, the total cost are around € 13 millions and 6 millions, respectively. Given this result, the study has given an insight for a mobile operator and telecommunication provider at ITERA to decide the network planning which is suitable both in technical and economic perspective and in the same time is able to provide services to the users which fulfill 5G technology standard.

Acknowledgement

This work has been supported by Penelitian Hibah Mandiri ITERA 2018. The authors thank to our colleagues at Lembaga Peneitian dan Pengabdian ITERA for the assistance so that this work can be completed.

References

[1] Carugi, Marco, “Key Features and Requirements of 5G/IMT-2020 Networks”, Internetsociety.org, February 2018.
[2] Andreev, Denis, “Overview of ITU-T Activities on 5G/IMT-2020, Saint Petersburg”, 2017.
[3] Patil, Manish, “5G Mobile Communications: Technology Enablers & Interference Mitigation Methods,” L & T Technology Services, 2015.

[4] Bogale, Tadilo E., Le, Long Bao, "Massive MIMO and Millimeter Wave for 5G Wireless HetNet: Potentials and Challenges," *IEEE Vehicular Technology Magazine*, vol. 11, pp. 64–75, February 2016, DOI: 10.1109/MVT.2015.2496240

[5] Osseiran, A., Boccardi, F., Braun, V., Kusume, K., Marsch, P., "Scenarios for 5G Mobile and Wireless Communications: The Visions of The METIS Project," *IEEE Communications Magazine*, pp. 26–35, May 2014, DOI: 10.1109/MCOM.2014.6815890.

[6] Jundhare, Mayuri D., Kulkarni, A. V., "An Overview and Current Development of Femtocells in 5G Technology," *IEEE International Conference on Advances in Electronics, Communication and Computer Technology (ICAECCT)*, India, December 2016, DOI: 10.1109/ICAECCT.2016.7942583.

[7] Bjornson, Emil., Bengtsson, Mats., Ottersten, Bjorn., "Optimal Multiuser Transmit Beamforming: A Difficult Problem with a Simple Solution Structure," *IEEE Signal Processing Magazine*, Vol. 31, pp. 142–148, June 2014, DOI: 10.1109/MSP.2014.2312183.

[8] Ghoul, Smail., Weijia, Jia., "Techno-economic Analysis and Prediction for the Deployment of 5G Mobile Network," 2017, *20th Conference on Innovations in Clouds, Internet and Networks (ICIN)*, Paris, March 2017, DOI: 10.1109/ICIN.2017.7899243.

[9] Bouras, Christos., Kokkalis Stylianos., Kollia, Anastasia., Papazois., Andreas., "Techno-economic Comparison of MIMO and DAS Cost Model in 5G Network," *11th IFIP Wireless and Mobile Networking Conference (WMNC)*, 2018, DOI: 10.23919/WMNC.2018.8480920.

[10] "Future Mobile Data Usage and Traffic Growth," Ericsson's Mobility Report,, 2017.

[11] Ozbek, Berna, Bayrak, Ugur., "Joint Beamforming and Power Control Technique for Femtocell Networks," *Wireless Personal Communication*, Vol. 95, pp. 4903–4916, August 2017, DOI: 10.1007/s11277-017-4131-5.

[12] Gemalto, "Introducing 5G Networks - Characteristics and Usages," February, 2016.