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Telecommunications energy and greenhouse gas emissions management for future network growth

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HIGHLIGHTS

- Model to evaluate key interdependencies of a fast growing telecommunications network.
- Network growth analysis using real data and Monte Carlo simulation.
- Importance of both operational and embodied energy efficiency improvements.
- Embodied energy expected to dominate in the future under current energy efficiency trends.
- Carbon footprint and energy management through optimum network replacement cycle.

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ABSTRACT

A key aspect of greener network deployment is how to achieve sustainable growth of a telecommunications network, both in terms of operational and embodied energy. Hence, in this paper we investigate how the overall energy consumption and greenhouse gas emissions of a fast growing telecommunications network can be minimized. Due to the complexities in modeling the embodied energy of networks, this aspect of energy consumption has received limited attention by network operators. Here, we present the first model to evaluate the interdependencies of the four main contributing factors in managing the sustainable growth of a telecommunications network: (i) the network's operational energy consumption; (ii) the embodied energy of network equipment; (iii) network traffic growth; and (iv) the expected energy efficiency improvements in both the operational and embodied phases. Using Monte Carlo techniques with real network data, our results demonstrate that under the current trends in overall energy efficiency improvements the network embodied energy will account for over 40% of the total network energy in 2025 compared to 20% in 2015. Further, we find that the optimum equipment replacement cycle, which will result in the lowest total network life cycle energy, is directly dependent on the technological progress in energy efficiency improvements of both operational and embodied phases. Our model and analysis highlight the need for a comprehensive approach to better understand the interactions between network growth, technological progress, equipment replacement lifetime, energy consumption, and the resulting carbon footprint.

1. Introduction

The amount of data carried by telecommunication networks is expected to continue to grow over the next decade at a rate of 25–45% per year [1,2] and the network operational energy consumption is expected to increase at an annual rate of 10% [3,4]. In recent years, scientists and researchers have dedicated significant research efforts to quantifying and managing the energy consumed by telecommunication networks. Current research on improving network energy efficiency is divided into two major themes: (1) operational energy efficiency, which aims to reduce the energy used in operating network equipment and devices [5–9] and (2) embodied energy efficiency, which aims to better manage the energy used in raw material acquisition and pre-processing, production, distribution, and end-of-life treatment of

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network equipment and devices [10–12]. However, both operational and embodied energy efficiency improvements should be jointly considered when managing the energy consumption of a rapidly growing telecommunications network because they are strongly related [8,13]. For example, *to benefit from the technological progress that improves the operational energy efficiency of network equipment requires network operators to frequently replace network equipment to realize operational energy savings. However, replacing network equipment frequently requires the production of new network equipment units and the disposal of outdated equipment, thereby increasing the embodied energy consumption of the network.*

Balancing the operational and embodied energy that is required is critical in managing the sustainable expansion of a rapidly growing network. The problem of balancing operational energy and embodied energy is also critical in other areas such as batteries used in electric vehicles [14] and the production and usage of emissions-free power plants [15]. In this paper, the sustainable growth of a network is taken to mean a growth strategy that minimizes the overall energy footprint of the network. This will provide the greatest opportunity for the network to grow in response to increasing demand for services in the longer term as the constraints on growth become more stringent due to resource depletion. Here, we focus on determining the optimal approach to network growth when accounting for the environmental (life cycle energy and greenhouse gas emissions) impact and the economic cost of the network growth. By minimizing the overall energy cost of the network, the optimal approach developed in this paper will also enhance the availability of services to populations who may not currently have access to digital services. As economic growth becomes more constrained by resource depletion, the provision of digital services in developing nations will need to recognize these constraints. Approaches similar to that described in this paper will provide the best opportunity to extend these services to these emerging economies.

Managing the sustainable growth of telecommunication networks requires careful consideration of four factors [13]: (i) the operational energy consumption of the network infrastructure; (ii) the embodied energy consumption required for network expansion and equipment renewal; (iii) the network traffic growth rate; and (iv) the technological progress in both operational and embodied energy efficiency improvements. Analyses have considered the interactions between (i) and (ii) [8,16], (ii) and (iv) [11,12,17,18], and (i), (iii), and (iv) [5–7,19]. However, *no analyses have been conducted to understand the interdependencies among all four factors in the sustainable growth of a network.*

In Section 2, we propose a new model, which can be used to evaluate the interdependencies of (i), (ii), (iii), and (iv) for better managing the life-cycle energy consumption and the resulting greenhouse gas emissions of a rapidly growing network. Without loss of generality, we use an example of a state-wide research and education network, i.e., the California Research and Education Network – CalREN, as the application focus for our energy model. However, the general model that we have developed can be applied to a wide range of different types of telecommunication networks. In addition, a critical assessment of the uncertainty in current trends of energy efficiency improvements (in both operational and embodied phases) is performed. The use of the Monte Carlo approach to deal with the uncertainty in parameters is also explained. In Section 3, we present the following analysis to understand the key interdependency factors in reducing the total network energy consumption to meet future network traffic growth. First, the results give insights into the rate of growth in the total life cycle energy of a growing network under current trends in energy efficiency improvements. Second, because network traffic growth is one of the main contributing factors in network deployment, we examine the impact of different network traffic growth rates to the total life-cycle energy of a network. To minimize the total life cycle energy of a network, the network operator has to make a decision on replacing legacy equipment with more energy-efficient equipment to gain network operational energy efficiency improvements. However, rapid replacement of network equipment units could potentially increase the network's embodied energy. Therefore, to help network operators in making an optimum decision of when to replace their network equipment, we investigate the impacts of energy efficiency improvements on the network equipment replacement strategy. Finally, Section 4 presents the conclusion of the paper.

2. Methods for managing the energy consumption of telecommunication networks

The total network energy consumption in year τ, $E^{(\tau)}_{total}$, is the sum of both network operational energy consumption ($E^{(\tau)}_{network}$) and the network embodied energy due to network deployment ($E^{(\tau)}_{embodied}$) in year τ: $E^{(\tau)}_{total} = E^{(\tau)}_{network} + E^{(\tau)}_{embodied}$.

2.1. Operating energy efficiency of a network

The network operating energy ($E_{network}$) is the integral of the total network power consumption over the duration of use (D):

$$E_{network}(D) = \int_0^D (P_{equipment}(t) + P_{overheads}(t))dt, \quad (1)$$

The total network operational power consumption consists of two components: the power consumption in operating network equipment that carries network traffic ($P_{equipment}$), and the power consumption in the overheads ($P_{overheads}$) that support normal network equipment operation (i.e., cooling network equipment, power distribution losses, and other overheads). Typical network equipment will consume a fixed offset power P_{base} when the network equipment has no traffic to process [20]. Beyond P_{base}, the power consumption of typical network equipment has an approximately linear dependence on the amount of data carried by the unit (in bits per second) [20]. Therefore, we assume that the power consumption of a network has a similar dependence on the amount of data carried by the network. As a result, the total network equipment power will take the following form:

$$P_{equipment}(t) = P_{base} + (P_{max} - P_{base}) \times \left(\frac{T(t)}{T_{max}}\right), \quad (2)$$

where P_{max} is the maximum network equipment power that occurs when the network traffic T is operating at its maximum load T_{max}. Inserting the equation for $P_{equipment}$ into Eq. (1) and implementing the integral gives the total equipment energy consumption over duration D:

$$\int_0^D P_{equipment}dt = P_{base}D + \frac{(P_{max} - P_{base})}{T_{max}} T_{ave}D = P_{equip,ave}D, \quad (3)$$

where T_{ave} is the average traffic through the equipment given by $\int_0^D Tdt/D$. The overheads are either constant or are approximately linearly dependent upon the equipment power given by the power usage effectiveness (PUE), defined as the ratio of the total power required for operating a network to the power used only by the network equipment [5]. Therefore, the equation can be simplified to the following:

$$E_{network}(D) \approx (P_{equip,ave} + P_{o/h,ave}) \times D, \quad (4)$$

where $P_{o/h,ave}$ is the yearly averaged overhead power when D is one year.