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Application association and load balancing to enhance energy efficiency in heterogeneous wireless networks☆

Yean-Fu Wen[a,*], Tzu-Heng Lien[a], FrankYeong-Sung Lin[b]

[a] Graduate Institute of Information Management, National Taipei University, New Taipei City, Taiwan ROC
[b] Department of Information Management, National Taiwan University, Taipei, Taiwan ROC

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ABSTRACT

Next-generation wireless networks enable the production of mobile devices that support various types of network. The coordinated multipoint (CoMP) technology enables mobile devices to connect to multiple access points (APs) and remote radio heads (RRHs). Achieving load balancing for running various types of application with various transmission characteristics has become critical to ensure energy efficiency of devices. This study presented a game-based analysis of applications and wireless network characteristics, and proposed an application-based weighted load-balancing wireless network association to reduce average energy consumption. To compare the energy efficiency and rotation fairness levels of various heterogeneous wireless network associations, three experimental scenarios were evaluated: i) random, ii) transmission-bound, and iii) intermittence-bound applications, with varying i) numbers of mobile devices, ii) numbers of RRHs, iii) numbers of Wi-Fi APs, and iv) signal ranges. Subsequently, based on the experimental results, the relevant concerns and findings were discussed.

1. Introduction

The rapid development and deployment of wireless network technologies have enabled users to access networks using numerous types of device, at any time, and from any location. In particular, fifth generation (5G) wireless networks enable users to use a mobile device (MD) with cellular and Wi-Fi networks, involving multiple-input–multiple-output (MIMO) technology with a high coverage rate [1]. In numerous situations, most users prefer to connect their MDs to Wi-Fi to enjoy high data transmission rates and minimal wireless transmission fees. However, 5G wireless networks support a low power consumption rate, which is determined by electrical energy used per time unit. Both fourth generation (4G) and 5G networks are widely integrated with existing Wi-Fi and LTE-Advanced (LTE-A) technologies to offer idiosyncratic advantages in transmitting, receiving, idle, and sleeping modes. In this study, we mainly investigated methods of improving energy efficiency for heterogeneous wireless networks, investigating the power consumption caused by various types of wireless network and application. Moreover, we performed load balancing between Wi-Fi and cellular networks to enhance energy efficiency.

Wi-Fi and cellular networks have different power consumption rates [2]. Typically, Wi-Fi networks such as IEEE 802.11n support a wide bandwidth, short coverage range, low moving speed, and low transmission power consumption. However, their idle power consumption is high because such systems lack sleeping mechanisms. By contrast, cellular networks such as LTE-A support low bit rates, wide coverage ranges, high moving speeds, and high levels of transmission power consumption; however, they offer lower

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* Corresponding author.
E-mail addresses: yeanfu@mail.ntpu.edu.tw (Y.-F. Wen), s710136110@webmail.ntpu.edu.tw (T.-H. Lien), yslin@im.ntu.edu.tw (F.-S. Lin).

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levels of standby and sleeping power consumption than Wi-Fi networks. Matching the transmission features of applications with wireless services is a major problem addressed in this study.

This study aimed to uniformly distribute the load among APs and base stations (BSs) (modified to eNodeBs and remote radio heads (RRHs) in 4G and 5G, respectively) to achieve load balance, such that the traffic load of each AP or BS was not higher than that of other devices. To minimise the traffic load among devices, the energy consumption should be low because power consumption does not increase linearly with the traffic load. The same traffic load with a high-level system load consumes higher power than with a low-level system load. Thus, load balancing lowers the traffic load on a given bandwidth, resulting in lower transmission power consumption.

Load balancing can improve the throughput, fairness, and utilisation while simultaneously reducing processing delays. Even with a simple load-balancing mechanism, considerable gains in call blocking and cell-edge user throughput can be obtained [3]. When two MDs with transmission-bound applications join a network, both MDs strive for a wide bandwidth. The optimal selection strategy is that one MD is connected to Wi-Fi and another is connected to a cellular network. The power range is adjusted according to the connected MDs that have the potential to reduce the power consumption as well as balance the traffic load [4]. A traffic load lower than other devices results in lower power consumption. Therefore, load balancing results in lower energy consumption.

The power consumption features of various types of application's throughput diverse wireless networks differ. In general, most applications are categorised as follows: i) transmission-bound applications that continuously send numerous packets over long period, such as video streaming; ii) central processing unit (CPU)-bound applications, such as video conversion or compression; and iii) input–output (IO)-bound applications, such as word count and text mining processes. Transmission-bound applications rely on a wide bandwidth to reduce the transmission time and power consumption. By contrast, intermittent-bound applications require short periods for transmission, thereby saving power if the user puts them into an idle state. How to match the requirements of running applications to the capacities of wireless networks is a major concern addressed in the proposed method [2]. This study concentrated on load balancing among Wi-Fi APs and cellular RRHs according to the needs of applications to achieve energy efficiency.

Three steps are used to achieve a status of ‘always optimal connection’: First, the required data are collected, comprising the performance of the MDs, types of application, and status of the network environment (i.e., bandwidth, delay, and weight of entrance from the user). Second, the collected data are entered into an algorithm to maintain the MD at the optimal connection status. Third, the MD is connected to an available wireless network, and then (if the current network is not optimal) another suitable network with an optimal status is selected. Step 2 of this study entailed adopting concentrated computing between RRHs and APs, in addition to distributed computing between MDs. The load-balancing scheme was implemented at a control centre with concentrated computing capabilities to balance the loads of the RRHs and APs. Cloud radio access network (C-RAN) architecture with software-defined networking (SDN) [5] was adopted. The weights were calculated and used to play a cooperative game that allocated wireless network resources among the MDs to achieve energy efficiency [6]. Subsequently, according to the data collected in Step 1, this study proposed algorithms for Step 2 as the association results for Step 3.

The contributions of this study are as follows:

- By matching the associative pairings between APs, RRHs, and MDs to suit the characteristics of applications and the heterogeneous load-balancing mechanism, our algorithm obtained lower energy consumption than that in relevant studies.
- By considering the characteristics of applications, namely the percentages of time distribution associated with transmitting, receiving, idle listening, and sleeping modes, our algorithm matched the power-conserving features of wireless access networks to the requirements of the MDs, thereby reducing the overall energy consumption of the system.
- By balancing loads among heterogeneous wireless networks from the viewpoints of telecommunication operators, our algorithm enhanced resource utilisation to support a high bandwidth for each MD. A simple rotation game was implemented to distribute the connection changes among the MDs.

The remainder of this paper is organised as follows. Section 2 reviews related work. Section 3 presents a description of network, power consumption, and response time models, in addition to presenting relevant problems. Section 4 introduces the proposed solution according to the characteristics of wireless network, the features of applications, weighted load-balancing mechanism, and power consumption model. Section 5 describes experiment cases, evaluation results, and discussions. Section 6 offers a conclusion with the future research directions.

2. Literature review

Wireless networks transmit data mainly through radio waves emitted from antennas. MIMO technology forms a mesh transmission environment that supports the connection of an MD to an RRH or AP through multiple links. Coordinated multipoint (CoMP) transmission extends the features of MIMO to connect multiple types of wireless network [7,8]. This study adopted the concept of CoMP to support heterogeneous wireless access association. The distance covered by each antenna varies across the transmission range, and the distance and speed of transmission vary across the channels provided by the network. This study described the transmission range for frequently used wireless networks, as well as multiple transmission bit rates. Because MDs may transmit data at varying bit rates, various resource distributions and diverse levels of feasibility are possible, enabling users to transmit and receive data at different rates.

The principles of wireless network switching include horizontal and vertical handoffs. A horizontal handoff involves network switching between wireless network environments of the same type based on the signal strength, whereas a vertical handoff entails