Computer Networks 134 (2018) 140–151

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Cell breathing algorithms for load balancing in Wi-Fi/cellular heterogeneous networks

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ARTICLE INFO

Article history:
Received 16 July 2017
Revised 23 November 2017
Accepted 23 January 2018
Available online 2 February 2018

Keywords:
Cell-breathing
Load balancing
Wi-Fi
Heterogeneous network
Offloading

ABSTRACT

As the data traffic demand increases exponentially, efficient and fair use of Wi-Fi networks together with the emerging cellular networks becomes a crucial topic. In this article, we first present novel cell-breathing based load balancing algorithms for Wi-Fi networks which provide full service availability. Then we enhance these algorithms to provide efficient offloading from cellular to Wi-Fi network in hot-spot areas. We also provide an efficient adaptive strategy for dynamic environments, where user distribution temporally changes. An extensive set of simulation results show that the proposed algorithms are very promising in satisfying min-max fairness and better user experience in Wi-Fi/Cellular heterogeneous networks.

1. Introduction

Rapid increase in mobile data traffic is going to place an extreme strain in cellular networks. This brings a significant challenge for the mobile network operators (MNO) who have to significantly enhance their infrastructure. However traditional network expansion techniques such as acquiring additional spectrum licenses or upgrading the technology is costly and time-consuming. A very promising alternative is to offload users from cellular network to Wi-Fi networks, which is considered as a cost-effective and energy-efficient solution which benefits both the operators and mobile users. Therefore, it is not surprising to see operators that have already built Wi-Fi offload networks proactively in areas with heavy mobile broadband usage such as universities. Current statistics indicate that 60% of total mobile traffic was offloaded in 2016 and this ratio is expected to increase in 2021. Moreover, Wi-Fi hotspots are expected to grow six-fold from 2016 to 2021 [1].

Nevertheless, in order to fully reap the rewards of reduced cost and better user experience, the MNOs need to ensure the Wi-Fi offloading capability as much as possible. Firstly, load balancing among Wi-Fi access points (AP) is very important in order to increase effectiveness of offloading. Moreover, it is beneficial that APs fully cover areas with heavy mobile data usage. However, APs should also not be overloaded by offloading too much data.

In this paper we first study the problem of load balancing among APs in a Wi-Fi network, while ensuring full coverage if possible. For this purpose we use cell breathing approach. Cell breathing is a well known concept in cellular networks and mostly in the context of CDMA networks. In CDMA networks, as the number of users increase, base station senses more interference and users need to transmit with higher power to maintain certain signal-to-interference ratio. This will also cause interference in neighboring cells and overall network capacity will decrease. To come up with a solution, the cell breathing approach was proposed [2,3], such that heavily loaded cells shrink their coverage areas and lightly loaded cells expand their coverage areas to attract users previously associated to heavily loaded cells.

The cell breathing technique can be implemented in WLANs by controlling the transmission power of AP beacon signals [4,5]. An overloaded AP will transmit beacon signals with low power and some of the users will connect to neighboring APs or may connect to cellular network if it is not in the coverage area of another AP. Note that transmission power of data packets is not reduced, so that this approach only affects the AP-user associations and does not affect the loss rate or sending rate of data packets.

All the APs in the Wi-Fi network communicate with an access controller (AC) in order to know their most appropriate beacon signal levels. AC calculates the beacon power levels according to some fairness criteria, such as min-max fairness [5], and inform the APs. Since Wi-Fi mostly provides cheaper access than cellular networks, it would be beneficial that APs provide full coverage. Full AP coverage will also eliminate need for costly vertical handovers. For this purpose, we propose to calculate minimum permissible

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https://doi.org/10.1016/j.comnet.2018.01.045

beacon power level for each AP, and ensure that beacon power levels of APs are never below these levels. We propose three different methods on how to set minimum permissible beacon power levels of APs, and propose three different load balancing algorithms accordingly. We provide a fairness comparison of these algorithms via an extensive set of simulations.

Although a load balancing technique is used, some of the APs may still have very high loads. In such cases, some of the traffic should not be admitted by the Wi-Fi Network and a portion of the users will only be served by the cellular network. To address this problem, we propose the following approach. In low load, Wi-Fi network serves to the whole region, while employing a cell-breathing based load balancing algorithm. However, if load of some APs are above a given threshold, then those overloaded APs are allowed to reduce their beacon power levels, even if some coverage holes occur and some of the users are only served by the cellular network. For this purpose, we extend the gap-free min-max load balancing algorithm that we proposed in the first part of this work, and provide congestion aware load balancing (CALB) algorithm for heterogeneous networks. CALB algorithm avoids existence of overloaded APs, while providing load balancing and high service availability in Wi-Fi network. We also provide an efficient adaptive strategy for dynamic environments, where user distribution temporally changes.

1.1. Related work

1.1.1. Load balancing in WLANs.

Load balancing mechanisms in WLANs can be classified into two categories: *client supported* and *network controlled*. In client-supported mechanisms, clients actively measure or passively learn the loads of APs and use these load information together with the received signal strength indicator (RSSI) in order to decide on which AP to use [6–11]. This kind of schemes has the advantage of requiring little or even no modification on APs. However, a significant disadvantage of these client supported schemes is that they require software or hardware modifications at the client side.

On the other hand, network controlled schemes employ a network-side entity to control the load of APs, and can achieve load balancing without any change in user equipment. Coverage adjustment algorithms proposed in [4,5,12] fall into this class. Bahl et al. [4] proposed a cell breathing algorithm to maximize the overall network throughput. They formulate cell breathing problem as mixed integer linear programming, assuming continuous beacon power levels. A later work by Bejerano et al. also considers cell breathing approach and aim to achieve min-max fair load balancing [5]. Different from Bahl et al., they assume that only discrete set of beacon power levels are feasible, which can be considered as more practical assumption. In [5], it is assumed that APs are located without causing gaps even if all the APs transmit at minimum power level. By assigning the minimum permissible power levels using radio coverage survey method, they provided a static solution to coverage whole issue. Recently, Wang et al. [12] take the service availability problem into consideration and present an optimization problem for cell breathing technique that minimizes the variance of all AP's loads under full service coverage constraints. They propose a polyhedron genetic algorithm which provides a near optimal beacon range for each AP with a service availability guarantee. Their algorithm sets the beacon power levels in a continuous manner, as in the case of [4].

In this work, we consider min-max load balancing problem similar to the problem considered in [5]. As in [5], we assume that only discrete set of power levels are feasible. What is novel in this study is that we incorporate a gap detection algorithm to load balancing algorithm. Further, based on the positions of APs and distribution of users, we propose several methods for setting minimum permissible beacon power levels in order to provide full service availability while providing load balancing among APs. Different than the previous studies based on cell breathing, we also consider heterogeneous Wi-Fi/cellular network case as described in the following part.

1.1.2. Load balancing in heterogeneous wireless networks.

User association and load balancing in heterogeneous networks is one of the significant issues to enhance spectral and energy efficiency for emerging 5G networks [13]. Andrews et al. [14] provides an overview of load balancing in heterogeneous networks (HetNets). Some of the recent studies exploit vertical handover (VHO) between two different wireless network technologies. In [15], when utilization of Wi-Fi Network exceeds above (or falls below) a given threshold, VHO is initiated to switch users from Wi-Fi network to cellular network (or vice versa) in order to keep load of APs in effective states. There are also other studies which consider service charges [16] or energy consumption [17] for VHO decisions. Ma and Ma [18] tries to balance the load in the whole system by admitting traffic to the tier-1 or tier-2 networks according to their utilization factors. They adopt a Call Admission Control (CAC) mechanism, such that a user is not admitted to a network if this network cannot provide sufficient QoS and no room can be opened for the new call via vertical handovers. This work aim to balance the utilization of different networks but they do not consider the energy or monetary cost of the users. Cell Range Expansion [19] is another approach for load balancing in heterogeneous networks. In this approach users are offloaded from large cells to smaller cells via an association bias. For example a small cell bias of 10 dB means that user equipment will associate with the small cell as long as its received power is more than the received power of macrocell base station minus 10 dB.

In this work, without loss of generality, we adopt the Wi-Fi-first approach [20], since Wi-Fi mainly offers low cost in terms of energy and money, and it would be preferable to keep more capacity in cellular networks. However, our proposed approach can be applicable after any kind of user association. We consider a loosely coupled system where cellular network and Wi-Fi network are independently deployed. However our load balancing scheme can also be applied to tightly coupled systems. For example, initial user association can be done according to a call admission scheme based on utilization factors as proposed in [18], and then the offered load balancing can be applied. Therefore, although our work primarily aim to balance the load of Wi-Fi Network with the maximum load constraint, it can be used complementarily with the algorithms that aim to balance the traffic load in the entire system.

The **main contributions** of this work are the following[1]: (i) we provide novel cell-breathing based load balancing algorithms in Wi-Fi Networks which provide full service availability, (ii) we enhance our algorithms to provide efficient offloading from cellular to Wi-Fi network in a WLAN/Cellular heterogeneous network, (iii) we adopt our proposed method to dynamic environment where users dynamically enter to or depart from the network, (iv) we provide extensive set of simulations to show the performance of provided techniques in terms of fairness and network utilization. To the best of our knowledge, this is the first work on load balancing in heterogeneous networks based on cell-breathing paradigm.

2. System model and problem definition

2.1. Wi-Fi network model

We consider a Wi-Fi network with a set of Access Points, $\mathcal{A}$, in a region R. Coverage areas of APs are assumed to be circular. There

[1] This paper is an extended version of our preliminary work presented in [21].