SDN Based Wireless Heterogeneous Network Management

Choong Seon Hong, S.M. Ahsan Kazmi, Seungil Moon and Nguyen Van Mui

Abstract The proliferation of novel network access devices and demand for high quality of service by the end users are proving to be insufficient for existing wireless heterogeneous networks, due to their inflexible and expensive equipment as well as complex and non-agile control plane. This article presents an architecture vision to address the challenges placed on future heterogeneous networks. Software defined networking is emerging as a solution for decoupling the control plane. Furthermore, it enables network function virtualization and network programmability which is very promising for meeting the high demands of end user. In this article, we present an SDN based management framework for cognitive heterogeneous networks. Moreover, we discuss the architectural changes, its control function and its interaction in detail. The proposed management framework enables optimal power control, resource allocation, interference management and provides end to end quality of service for its user.

Keywords Software defined networks · Cognitive radio networks · Hetrogenous networks · Network management

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1 Introduction

The modern wireless communication has empowered us in optimizing our operations, economics, health and all the modern industries. Life without it is beyond imagination due to our broad dependencies over the wireless networks. We gather, analyze and share a huge amount of information among different entities to have a productive life which was not possible before the advent of modern communication networks. In the last two decades wireless communication has evolved at a very rapid pace to keep up with the expectations and requirements of the users.

Cellular communication falls among the category which has received the most popularity among the wireless networks. The first generation of cellular networks started off with analog communication primarily for voice communication. The second generation was dominated by digital voice and a small amount of data communication while the third generation which was initially focused to increase the number of users in the network but observed a tsunami of data communication in the networks [1]. Today we have Third Generation Partnership Project (3GPP) Long Term Evolution (LTE), state of the art fourth generation cellular network. Our 4G standard along with voice carrying capability enables richer and real time data networks. Currently it is providing broadband services to 50 million users around the globe and is expected to support two billion users by end of 2018 [2]. New features are being analyzed and added in the latest release of LTE standard (release 13) to enhance the overall efficiency of the network [3]. This trend of data traffic in cellular networks is hopeful to grow even more because of the bandwidth hungry applications and proliferation of modern communication gadgets i.e. smart phones, tablets, smart watches, e-health, Internet gaming and etc. The mobile traffic has increased 66 times from 2009 to 2014 with an annual rate of increase of 131 % [4]. On the other hand, the data rates from third to fourth generation technology has increased only by 55 % annually [5]. This shows us the need to further investigate and develop new techniques to improve the current cellular networks.

One of the most recent and promising direction for enhancing the capacity of the network is the installation of small cells under the coverage of existing cellular network. This novel paradigm with different cell sizes is known as heterogeneous networks (HetNets). Additionally, there has been a significant amount of work claiming the effective and efficient use of installing a cognitive radio network (CRN) under the existing cellular network in [6, 7]. Furthermore, academic and industrial communities has started active research activities on the fifth generation (5G) communication technologies to meet the goals for future wireless networks. Various programs by different organizations are launched aimed at potential key technologies of 5G namely 5GNOW and METIS under European Telecommunications Standards Institute (ETSI) to meet the cellular requirements beyond 2020 [8]. The 5G standard keeping in view the trend of growth in traffic is investigating and providing guidelines for future cellular network. 5G is expected to handle 1000 times more data volume per unit area, 10–100 times higher number of connected devices, latency reduced to five times with guaranteed data rates up to multiple gigabit per second and battery life about 10 times longer than current state of the art [9]. According to [10], legacy cellular networks are not designed to handle such requirements so major changes are required to adopt the future cellular requirements. According to [11], one of the most promising aspect would be dense installation of small cells forming multiple HetNets which would play a vital part in fulfilling the requirements of future cellular networks.

Management of network in future HetNets will become one of the biggest and crucial challenge for efficient performance of the network. This broadly includes number of users per cell, small-cell placement, interference among cells, handover during mobility, scalability of networks, heterogeneous technologies and their interoperability issues and user association. If the future HetNet architecture can handle these tasks efficiently, goals of 5G network can be achieved. We in this article will consider the management of HetNets from Software defined networking (SDN) point of view.

Coordination and cooperation will play a vital role in operations especially with the dense small cells deployment as envisioned for 5G networks [12]. The existing LTE system has been designed to run as a distributed system where each cell takes all its decision. This distributed practice without taking into account neighbors information will cause serious inefficiencies in terms of performance. Thus, coordination of control plane is required to efficiently carry out network operations [4]. The concept of an SDN controller has revolutionized the network world especially in wired domain which primarily decouples the control and data plane. This concept looks very promising for the wireless and mobile communication domain and a number of studies are being conducted to adopt the SDN paradigm in mobile networks [12, 13]. Similarly, in [14], a central coordinator (standardized by 3GPP) is used, namely femto management system (FMS) to cooperate femto-cells within geographical proximity in order to allocate resources while protecting them from interference. The biggest challenge in central coordination is the message passing which consumes a significant amount of bandwidth in back-haul if a completely centralized solution is used. However, small cells are typically low power cheap devices and can be connected via broadband services through Internet to coordinate and cooperate. This saves significant bandwidth which would be used for message passing if back-haul is used. Furthermore, an analysis performed on a macro-cell with 20 micro-cell with 50 clients holding 10 flows claims that only 500 Mbps bandwidth was found suitable for layer 1 coordination and considering the advances in the communication world this bandwidth is not very high especially in fiber communication [15].

The rest of the article is organized as follows: Section 2 discusses the current and future HetNet architecture. In Sect. 3, we provide the SDN based management framework and its functions which will help in achieving the goals for the future HetNet architecture. Section 4, finally concludes this article.

2 Legacy and Future HetNet Architecture

The existing or the legacy HetNet typically consists of multiple small cells under the coverage of a macrocell as shown in Fig. 1. These small cells can be categorized in terms of their transmission power levels, cell range, access techniques, modulation techniques, sensing capabilities and etc. Some typical examples include micro, femto, pico, cognitive and WiFi transmitter as shown in Fig. 1. In the existing HetNets, coordination among different cells is typically done at the bases station in order for the network to operate efficiently. However in the existing HetNets, the number of small cells in a network are very scarce so coordination overhead among different cells is relatively less which will not be the case for the future. This makes management of HetNets a very important aspect for future wireless HetNets.

The main motivation for dense installation of small cells comes from the fact that increasing the number of macrocells is costly and ineffective since around 50 % of voice calls and 70 % of data usage currently takes place indoors where up to 20 dB penetration loss reduces the outdoor to indoor signal strength [13]. Therefore, installing indoor small cells increases the efficiency of the network if managed properly. Additionally, the novel wireless technologies i.e., device to device communication (D2D), massive multi input multi output (MIMO), cognitive radio network (CRN), millimeter-wave band communication and etc. will also be a part of future HetNets along with dense installation of small cells as shown in Fig. 1. This makes management of HetNets very vital especially for interference, networking congestion and spectrum allocation problems. The use of different functional network devices like switches, routers which is making the network architecture much more complex and difficult to handle. Some recent studies address dynamic infrastructure and flexible allocation of network resource on demand which calls for a new management framework as the existing cellular management framework was not designed for these HetNets.

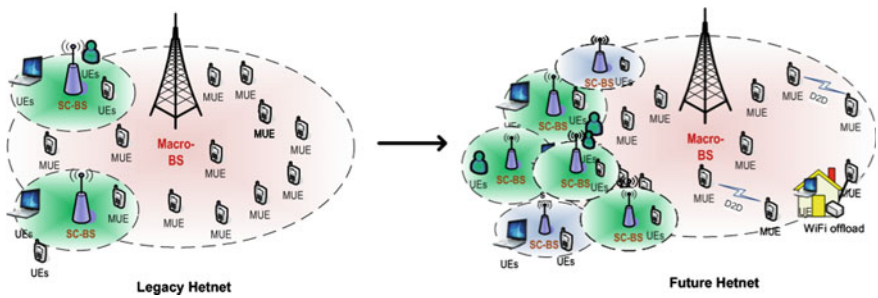

Fig. 1 Evolution of HetNet architecture

3 SDN Based Management Framework

Software-defined Network (SDN) with OpenFlow protocol which provides a dynamic and flexible network architecture to help todays static network evolve into an extensible service delivery. SDN refers to a network infrastructure in which control plane is separated from physical topology. The SDN enables us to develop a centralized traffic engineering, power control and spectrum selection protocol that needs to communicate among end-users, base-stations and SDN controller to achieve higher data delivery throughput, higher reliability and energy efficiency with excellent capability of spectrum utilization.

The SDN controller can have a number of functions depending upon the network operator policy both as internal or as an external application (using an application programmable interface (API) for external applications). The advantage of using SDN in heterogeneous networks is that incumbent devices (BSs, CPEs, SUs, Mesh routers, Mobile ad hoc Users) are re-designed to communicate with SDN controller so that their network policies are updated on the fly, leading to maximization of agency interoperability. Therefore, all networking devices have an agent installed in it to coordinate and cooperate among cells. The communication between the SDN controller and the agents can use the API concept as in [8]. However, the Open Network Foundation (ONF) is working on the OpenFlow extension standardization for wireless and mobile networks [13].

In this article, we would present an SDN based management framework proposed specifically for heterogeneous cognitive networks as shown in Fig. 2.

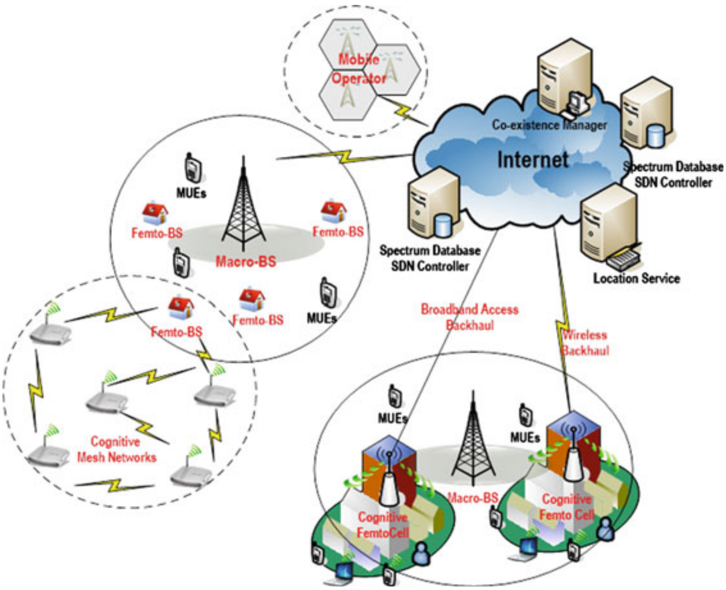

Fig. 2 Overview of a SDN-based heterogeneous cognitive network

The core functions and the working of the framework is discussed in detail. The proposed framework will provide a network resource optimization framework and efficient control mechanism based on SDN for such cognitive heterogeneous networks. It can provide centralized traffic engineering, power control and spectrum selection protocol that needs to communicate among end-users, BSs and SDN controller to achieve higher data delivery throughput, higher reliability and energy efficiency with excellent capability of spectrum utilization. The design of SDN-based cognitive heterogeneous networks necessitates substantial modification in the Physical layer and MAC layer software modules and couples with Routing Protocol. We do strongly claim that the framework would show high performance in a large number of cognitive applications, particularly for those emergency applications requiring high data rate, reliability, mobility and reduced end-to-end delay but spectrum shortage and short coverage such as vehicular, battlefield surveillance, disaster recovery, medical care, radioactive leakage detection, etc.

The framework separates control and data plane to obtain interoperability and scalability and provide sufficient services to each different kinds of user. SDN Controller can optimize the whole heterogeneous network by jointly considering:

1. Power Optimization Control and Interference mitigation: Based on information from spectrum database and co-existence Manager, SDN Controller optimally allocates transmission powers to each users and base station in the network to mitigate interference. Moreover, both users and base stations in the network adjusts its power in order to save energy and protects primary users.
2. Resource Allocation: Due to self-coexistence of multiple wireless radio access networks, SDN controller must perform the resource allocation optimization to maximize overall throughput. Each user/basestation can use a range of contiguous channels (i.e. channel bonding) to increase its capacity.
3. End-to-End QoS: SDN controller dynamically monitors a connection and allocate more channels or transmission power for related-users to ensure end-to-end QoS.

3.1 Controller Plane Architecture and Functions

In this section we discuss about the control plane architecture and the core functions which are build over the SDN controller as shown in Figs. 3 and 4. In Fig. 3, we can see that base stations are attached to the SDN controller which include both the licensed and unlicensed base station with heterogeneous capabilities. Furthermore, we describe the functionalities in detail for the SDN controller.

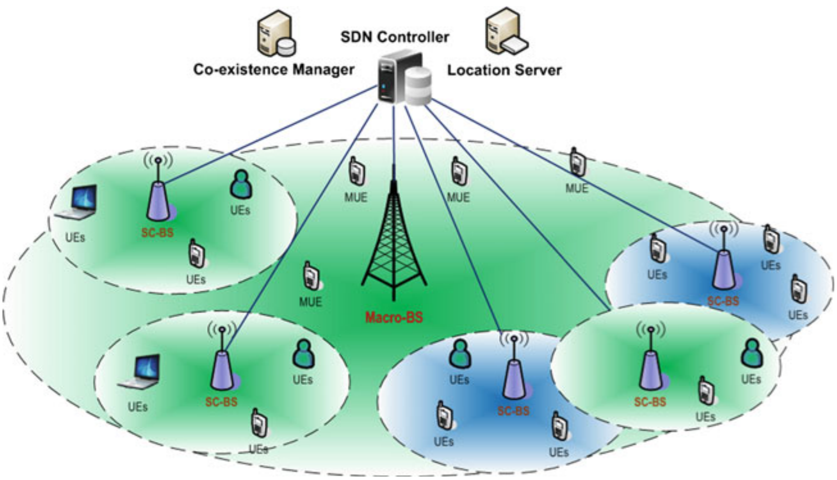

Fig. 3 Control plane architecture

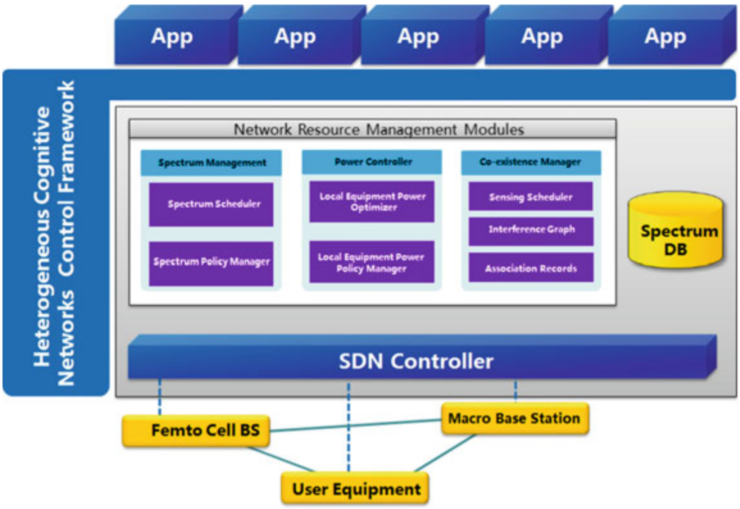

Fig. 4 SDN controller architecture for SDN-based heterogeneous CRN

3.1.1 Spectrum Management

1. Spectrum Scheduler (SS): It schedules spectrum hole usage in time, space to deploy co-existence of multiple small cells i.e., femtocells for different network operators.
2. Spectrum Policy Manager (SPM): It stores and updates meaningful data and policy-related radio parameters including protected channel numbers,

geo-location and contour of a base station, geo-location of cellular sites, terrain curvatures of the service region, maximum EIRP on allowed cellular channels, antenna height and gain, propagation models, interference scenarios, mobile devices and their geo-locations, transmission power and operating channels. SPM regularly updates information from broadcasters, regulators and service providers. The database can be pulled by or pushed directly/in-directly via BS to cognitive devices.
3. Spectrum Allocation Optimizer (SPO): It dynamically perform spectrum allocation optimization based on geo-location of cognitive devices, demand for bandwidth per each end-user, spectrum policies. SPO will adjust spectrum prices and broadcast to end-users.

3.1.2 Power Controller Manager

1. Local Equipment Power Optimizer (LEPO): It is based on power policies and strategies, LEPO optimally calculates transmission power ranges for end-users per spectrum hole.
2. Local Equipment Power Policy Manager (LEPM): It stores and updates the policy-related power parameters from broadcasters, regulators and cellular service providers. LEPM will make power strategies for each secondary system using spectrum holes for co-existence and incumbent protection.
3. Local Equipment Power Controller: It dynamically adjust transmission power levels in each users power ranges to support mobility and increase energy efficiency.

3.1.3 Coexistence Manager

1. Sensing Scheduler (SS): As multiple spectrum bands are available but due to the limited number of network interface per user, SS must optimally schedule the time and frequency to perform sensing at each end-user.
2. Interference Mitigator (IM): Based of analyzing the spectrum behavior and the performance metric of user devices, IM makes access strategies on each band for each user device to mitigate interference.
3. Route Manager (RM): Based on spectrum policies and power strategies, and end-user demands, RM calculates the feasible routes with the different costs and utilities for each user.
4. QoS Manager (QoSM): After establishing connection, QoSM will ensure end-to-end QoS for that connection by requesting more bandwidth to SPO for backhaul link. QoSM dynamically monitors the end to end user demands and provide services.

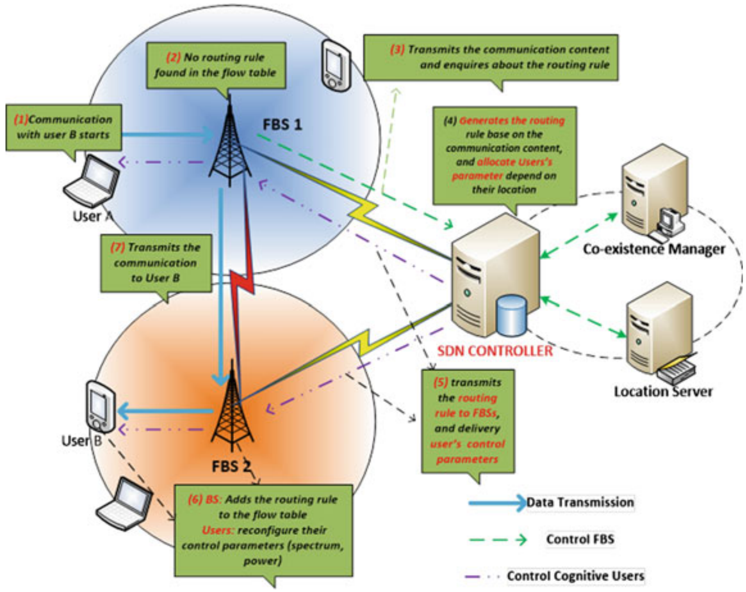

Fig. 5 Scenario: control plane interaction

3.2 Scenario: Control Plane Interaction

This section describes a scenario of control plane interaction between a cognitive user-device A connected to a femto base station 1 (FBS 1) and wants to communicate to cognitive user-device B which is connected to FBS 2 as shown in Fig. 5. Initially, user A sends request to its FBS 1 which is forwarded to the SDN controller for evaluation and allocation of power and channel. The SDN controller after evaluation send a route reply which consists of the route and the user's control parameters to concerned FBSs which installs the route in its table for future routing. Finally, FBS 1 transmits which initiates the actual exchange of data transmission as shown in Fig. 5.

4 Conclusion

The tremendous growth in wireless world due to the introduction of smart devices and associated bandwidth-hungry applications is forcing the service providers to enhance their existing network capabilities. The service providers need to support a high-capacity, agile, low-cost solution to ensure both user satisfaction and their profitability. This article introduces an SDN based framework for heterogeneous networks with network control capabilities to allow optimal power control, resource allocation, interference management and end to end quality of service.

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