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Dynamic Clustering Protocol for coordinated tethering over cellular networks

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A B S T R A C T

Tethering has been recently proposed as an efficient solution for the increase in number of mobile users and the requested bandwidth in cellular networks. The idea is to group the mobile nodes into clusters, each containing slaves served by a hotspot. To save licensed spectrum, the hotspot–slave link can use other frequency channels like the newly vacated TV white space (TVWS) bands. A recent work has proposed an iterative clustering algorithm for cellular networks. Despite its computational complexity and signaling overhead, this algorithm did not handle the nodes' mobility inside the cell neither the change in their required data rate. In this work, we propose a new dynamic protocol for clustering the nodes taking into account the possible changes occurring in a cellular network. Specifically, the Dynamic Clustering Protocol (DCP) adapts the network configuration with the variable mobiles' requirements and the different network events. This will reduce the needed time and signaling and offers better service quality for the clustered users. After presenting the various network events, the handover scenarios and signaling for the Dynamic Clustering Protocol, the performance of the proposed protocol is studied. This was accomplished by modeling different network scenarios and computing the required number of handovers as a function of user mobility, available network resources and data rate requirements for a given clustered nodes configuration.

1. Introduction

To extend the coverage and improve the throughput and reliability of the network, relaying has emerged as an effective solution to enhance the performance of new generation of cellular networks (Nabar et al., 2004; Laneman et al., 2004). Most of the research works related to relay channels have considered installation of fixed relay stations in infrastructure-based wireless networks (Liu et al., 2006; Adinoyi and Yanikomeroglu, 2007). However, recent studies have investigated moving relay nodes by considering the users' mobile stations as mobile relays (Nourizadeh et al., 2006; Raghothaman et al., 2011; Hossain et al., 2008; Muñoz et al., 2010). A performance evaluation of network architecture with mobile relay stations was realized in Hossain et al. (2008) and compared with fixed relay stations in Nourizadeh et al. (2006). In Raghothaman et al. (2011), the authors have proposed a comprehensive system architecture for Long Term Evolution (LTE) system that enables mobile-to-mobile communications for the purpose of enhancing the capacity of cellular networks. Furthermore, Muñoz et al., (2010) has investigated through field testing, the performance benefits and improvements of multi-hop cellular networks using mobile relays over traditional cellular systems. In addition, papers by Coll-Perales and Gozalvez (2011) and Kim and Cho (2009) have shown potential improvement of handover (HO) performance in cellular systems with the use of relay nodes.

Tethering was lately used over WiFi to grant internet access to a user via another connected device. Tethering became achievable in cellular networks with the abundance subsistence of mobile devices like smart phones, tablets and laptops. Because coordinated tethering make use of existing devices and thus does not require any additional infrastructure in the network, it provides a more flexible and affordable solution than relaying.

To combat the spectrum shortage, researchers and industry are searching for new possible frequency bands to be used in cellular networks. Some attractive options are the lately vacated television bands and the unused broadcast television spectra available between 50 and 700 MHz referred to as TV white-space (TVWS) (Dudda and Irnich, 2012; Fujii et al., 2012; Deaton et al., 2012). Furthermore, this frequency range offers better radio propagation properties than frequencies utilized in LTE, because it occurs in

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lower band (Murty et al., 2012). The authors in Dudda and Irnich (2012) and Fujii et al. (2012) have investigated the potential gains of deploying cellular networks in the TVWS band. Moreover, mechanisms for LTE coexistence in TVWS that dynamically share the spectrum with other secondary users were proposed in Beluri et al., (2012). And in De Beek et al. (2012), the authors studied several use case scenarios of LTE deployment in TVWS spectra in Europe.

Recently, the authors in Tabrizi et al. (2013) have proposed a coordinated tethering algorithm to deliver data to a destination node (called slave) through an intermediate nearby device (called hotspot).

While WiFi-based ad hoc relaying proposed in Todd and Zhao (2003) considered that only inactive mobile node could be selected as hotspot and could relay only one node at a time, the proposed algorithm in Tabrizi et al. (2013) allows any node to act as a hotspot and to assist more than one slave. The clustering algorithm groups iteratively the connected nodes in a cell into clusters. Each cluster consists of a mobile hotspot connected to the BS via LTE. In a cluster, they may exist some slaves attached to the hotspot and communicating with it over TVWS. The hotspot serves as a relay to provide the connected slaves with broadband access to the BS.

The proposed algorithm provides connectivity to mobile users by coordinating users, selecting hotspots and managing interference. However, in Tabrizi et al. (2013), the nodes' mobility and the data rate variation were not taken into consideration. Moreover, the authors have not indicated how to manage the different networks event that can occur in the cell like the arrival of new users or the disconnection of a hotspot. Due to its iterative nature, the clustering algorithm would take a prohibitive time for real-time communications. Therefore, it will not be possible to launch the clustering procedure each time a network event takes place.

In this paper, we will consider all the possible network events that will arise in the tethering context and propose a new Dynamic Clustering Protocol (DCP). In the proposed protocol, a mobile node, being a slave or a hotspot, will not undergo the clustering algorithm but will simply perform a handover whenever needed. The proposed DCP protocol will operate on a given clustered nodes configuration and will consider the mobile nodes requirements and the varying networks conditions as well to perform the handover accordingly. This will provide the mobile node with a better connectivity eliminating the need to wait for the re-clustering algorithm from one side and minimizing the cost of operating on other nodes in the re-clustering process from the other side.

The paper is organized as follows. In Section 2, the system model and the proposed algorithm for clustering in Tabrizi et al. (2013) are presented. The new protocol for dynamic clustering network is described in Section 3 along with the networks events that will trigger the different handover scenarios. The handover signaling schemes are elaborated in Section 4. Then, simulation results are given in Section 5 that shows the needed number of HO for different user case scenarios. Finally, we conclude in Section 6.

2. System model

We consider a cell of an LTE network with U mobile users divided into hotspots and slaves as shown in Fig. 1. The BS will communicate with the hotspots over one of the N allocated LTE frequencies. And each hotspot will be linked with its corresponding slaves using one of the M available TVWS bands. In this way, clusters comparable to small cells, are formed in the original cell as can be seen in Fig. 1. Moreover, each node is assumed to be able to operate on both LTE and TVWS bands with the same cellular access technology.

Grouping the nodes into clusters will decrease the total transmission power and allow frequency reuse among the clusters. Moreover, the cell coverage is enlarged by reducing the path-loss while choosing the hotspots closer to the slaves than the BS. Also, the network capacity can be expanded: a single BS in the cell can serve more users with the help of the hotspots connected to their slaves over TVWS frequencies. In this paper, it is assumed that each of the M TVWS bands can be used only in one cluster. Therefore, no frequency reuse is considered between the clusters.

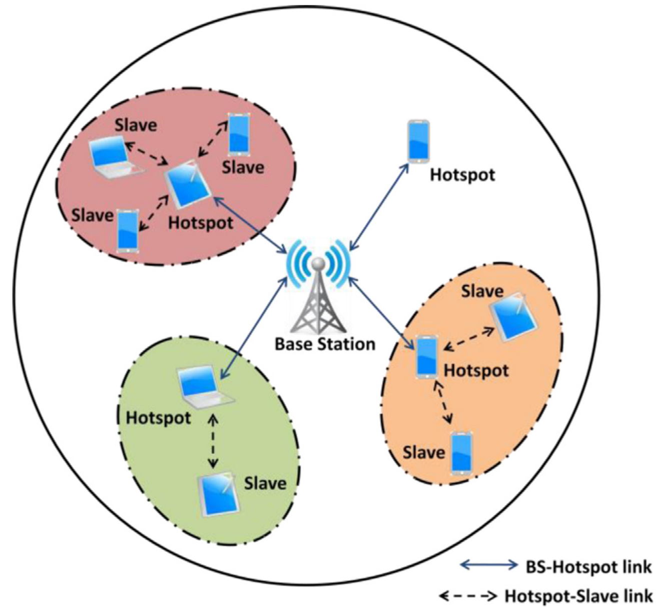

Fig. 1. Clusters formed in a macrocell.

The clustering algorithm proposed in Tabrizi et al. (2013) will be explained briefly hereafter.

Actually, the algorithm will iteratively cluster the nodes by identifying the hotspots with their respective slaves and verifying the feasibility of the configuration in terms of resource allocation. The algorithm consists of five main steps.

In the first step, the clustering configuration of the nodes is determined such that it minimizes the overall network transmission power. The clustering is performed by the BS based on the average channel gains g_{ij} of the different links BS-nodes and nodes-nodes.

Then, the remaining four steps aim at verifying that the clustering is feasible with the available resources while preserving the service requirements of different users like power and rate. If the configuration prove to be not possible, then step 1 (clustering) is performed again taking into consideration the nodes that did not meet their requirements.

However, the clustering algorithm presented above has some drawbacks. First, it is complex and requires a large amount of time in order to be completed. This is because several iterations may be needed to determine the different clusters. Also, at each iteration, many optimization problems are performed to verify the different constraints on resource allocation and on power and rate requirements in the clusters.

Moreover, this proposed method does not take into consideration important cellular events like the mobility of the nodes, the arrival of a new node or a node leaving the cell.

To take care of such changes, one solution is to perform a re-clustering periodically and more often. But, this solution is costly because of the time consumed by the algorithm and the signaling overhead that takes to reassign all the nodes as hotspots or slaves.

Therefore, here, we propose to detect any network change and to solve it without the need to trigger the iterative clustering algorithm. This way, the proposed Dynamic Clustering Protocol (DCP) will perform successively local changes in the cell whenever