Computer Communications 32 (2009) 703–711

Contents lists available at ScienceDirect

Computer Communications

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

Resource management policies for fixed relays in cellular networks ☆

Won-Hyoung Park *,[1], Saewoong Bahk

School of Electrical Engineering and Institute of New Media & Communications, Seoul National University, Seoul 151-744, Republic of Korea

ARTICLE INFO

Article history:
Received 12 October 2007
Received in revised form 25 November 2008
Accepted 27 November 2008
Available online 10 December 2008

Keywords:
Cellular networks
Fixed relay
Resource reuse
Path selection
Spectral efficiency

ABSTRACT

Mobile stations in the cell boundary experience poor spectral efficiency due to the path loss and interference from adjacent cells. Therefore, satisfying QoS requirements of each MS at the cell boundary has been an important issue. To resolve this spectral efficiency problem at the cell boundary, deploying fixed relay stations has been actively considered. In this paper, we consider radio resource management policies concerned with fixed relays that include path selection rules, frequency reuse pattern matching, and frame transmission pattern matching among cells. We evaluate performance of each policy by varying parameter values such as relay station's position and frequency reuse factor. Through Monte Carlo simulations and mathematical analysis, we suggest some optimal parameter values for each policy and discuss some implementation issues that need to be considered in practical deployment of relay stations.

1. Introduction

Mobile communication service providers are planning to deploy systems capable of provisioning high bandwidth. As candidate systems, they strongly consider high speed downlink packet access (HSDPA) systems of the 3rd Generation Partnership Project (3GPP) [1] and IEEE 802.16 based systems [2] of Worldwide Interoperability for Microwave Access (WIMAX) [3] and Wireless Broadband (WiBro) [4]. IEEE 802.16 recently has started a task group 802.16j for mobile multi-hop relays [5]. We expect IEEE 802.16 standard based relay products to be available in a couple of years.

The 4th Generation (4G) systems have the requirements of the cell capacity of up to 1 Gb/s for nomadic users and 100 Mb/s for fast moving mobile stations (MSs) [6]. International Telecommunication Union Radiocommunication Sector Working Party 8F (ITU-R WP8F) has been working on the requirements of the system beyond IMT-2000 which is now called IMT-Advanced [7]. IEEE 802.16 will start a new task group 802.16m that plans to generate the enhanced version of the 802.16 standard that meets the requirements of IMT-Advanced [8]. In such networks, each user expects high throughput to enjoy various multimedia services regardless of its mobility and location. However, the cellular architecture has a structural weakness in providing fair service because each user's QoS depends on its location and mobility within the cell. If an MS is near the cell boundary, it experiences severe path loss and poor spectral efficiency compared to MSs near the base station (BS). So more resources need to be allocated for cell boundary users to obtain the same throughput. This unfairness problem is currently being considered in the 4G system design as each MS's requirements get tougher.

A simple way to overcome the path loss is to divide a long path into multiple shorter hops and use relay stations (RSs) for data delivery. Deployment of more RSs makes each hop distance shorter. If the distance of each hop is short enough, then each transmission can achieve higher spectral efficiency and more concurrent transmissions can be possible in the same region. These factors can increase the spectral efficiency of the MSs near the cell boundary. Researchers have investigated the advantage of using fixed relays in cellular systems [9–11]. In [9], the general overview of multi-hop relaying is given. An operation scenario in a Manhattan-like city area and its preliminary performance results are also presented. In [10], an interference management technique for the cellular system with fixed relays which requires only the channel allocation information of the relays within the cell is proposed. Its approach is the same as that in dynamic frequency hopping (DFH) [12], which generates frequency hopping patterns based on interference measurements from all the adjacent cells. Its computational complexity is lower but throughput performance is degraded as it uses much less information than DFH. In [11], a preconfigured relaying channel selection algorithm is proposed. It exploits the channel reuse in a controlled manner to prevent the

☆ This work was presented in part at the IEEE Globecom'06, San Francisco, USA.

* Corresponding author. Tel.: +8228808434; fax: +8228808214.
E-mail addresses: pwh@netlab.snu.ac.kr (W.-H. Park), sbahk@netlab.snu.ac.kr (S. Bahk).

[1] W.-H. Park was with the Telecommunication R&D Center, Samsung Electronics, Suwon, Korea. He is now also with Future Business R&D Center, SK Telecom, Seoul, Korea.

0140-3664/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.comcom.2008.11.039

co-channel interference. However, its channel partitioning pattern is not flexible and requires coordination among base stations. So it is not able to adapt to the variations of traffic loading.

Depending on the functionality of the RS, there are two well-known methods in transmitting the relaying signal. One is amplify-and-forward (AF) which requires the RS to have only RF amplifier and the other is decode-and-forward (DF) which requires the RS to decode the signal first, then to re-encode and transmit [13]. There is also a possibility of exploiting the diversity using relays, which introduces the cooperative relaying [14]. The destination node can decode the original signal by combining several signals from multiple relays possibly including the original source.

The performance improvement by functioning an MS as relay is shown in [15]. It demonstrates the advantage of this approach well, but there are many issues to be resolved in practical systems that include the design of more intelligent and complicated protocols for MAC, routing, billing, etc. It shows that the throughput gain by using the multi-hop relaying is mainly achieved by two-hop paths. The gain of using the paths of longer than three hops is very little, hence we do not consider the case of using more than three hops in this paper. It also presents that the concurrent relaying can improve the throughput substantially if it is exploited effectively. The concurrent transmissions over paths within four hops and the two two-hop paths is investigated. However, it does not elaborate how the concurrent relaying should be applied in the cellular system in general. We suggest a method for concurrent relaying pattern using an appropriate frequency reuse factor among RSs.

In this paper, we mainly compare the performance of two-hop relaying with that of direct communication. We assume that RSs are placed at the line-of-sight from the BS. With the relay's help, an MS can get a sufficient data rate without experiencing the outage even at the cell boundary where the received signal strength from the BS is too weak. However, there is a drawback of using relays. That is, it consumes more resources compared to using the direct path. Therefore, we design a decision rule for when the relay path should be chosen in preference to the direct path. We consider two types of path selection rules (PSRs) and compare their performances.

When an RS transmits, it covers a smaller region than the BS does. So the same frequency band can be spatially reused in some other RS areas within the cell, which necessitates a frequency reuse method. In this paper we consider four reuse patterns among RSs, and radio resource management (RRM) policies such as frequency reuse pattern matching and frame transmission pattern matching among cells.

The rest of this paper is organized as follows. Section 2 describes the system model and Section 3 discusses RRM policies. Section 4 presents a Monte Carlo simulation algorithm and simulation results. Section 5 considers some practical issues for the deployment, and we conclude in Section 6.

2. System model

In our model, a BS is located at the center of a cell. There are six RSs within the cell, each with distance R apart from the BS and equally separated as shown in Fig. 1. Each cell is logically divided into six sectors and each of which is covered by one RS.

2.1. Frame transmission and frequency reuse patterns among RSs

We assume that a frame can be transmitted in infinitesimal granularity in time and/or frequency domain and there is no inter-frequency interference. We consider two types of transmission pattern: time and/or frequency division as shown in Fig. 1. In frame transmission type 1 (FTT1), the BS transmits downlink traffic over the whole cell area. All the RSs and MSs within the cell hear the same data transmission from the BS. For uplink traffic, each RS and MS transmit towards the BS with the frequency reuse factor (FRF) of 1. In FTT2, the BS transmits downlink traffic by using the same power as the RS does. So we regard each cell as seven small cells and apply the same FRF pattern as in a legacy cellular system.

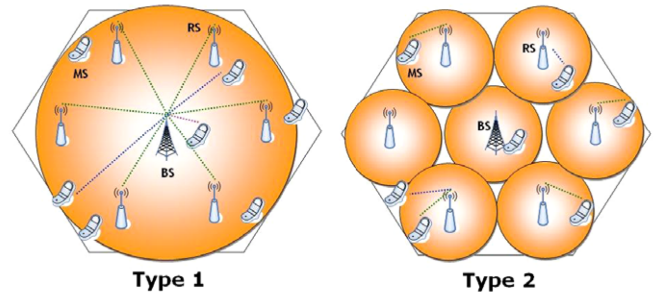

Fig. 1. Frame transmission types.

However, there is a critical difference between the legacy cellular system and the system where the BS acts like an RS in FTT2. The distance between an RS and a neighboring RS or the BS may vary in reality because the RS is not necessarily deployed in such regular and symmetric patterns as BSs. This makes the legacy FRF pattern among BSs impractical in the cellular network with relays. So we focus on the FRF pattern among the RSs within the cell. We assume that in FTT2 the RS can transmit downlink traffic to an MS within the RS's coverage. When the BS does not transmit, a local frequency reuse pattern for each RS needs to be considered. Fig. 2 depicts the examples of FRF pattern. For $FRF = x$, each RS is able to use $1/x$ of each frame and the other RSs can reuse resources by a factor of up to $6/x$.

2.2. Positioning of RSs and channel capacity

The distance R between the BS and an RS is a critical parameter that affects overall system performance. If RSs are close to the BS and the interference between RSs becomes high, MSs near the cell boundary are not able to exploit spatial reuse effectively. On the other hand, if RSs are located near the cell boundary, they are interfered with RSs in adjacent cells, resulting in reduced RS's coverage. Considering the interference, spatial reuse and spectral efficiency together, we can decide an optimal R.

Without considering the shadowing and fast fading, we can express the received power P at distance d from the transmitter as

$$P = P_0\left(\frac{d}{d_0}\right)^{-\gamma}, \tag{1}$$

where P_0 is the received power at distance d_0. The path loss exponent γ is set to 2.7 for the line-of-sight (LOS) path, and 3.5 for the non-line-of-sight (NLOS) path. In general, γ is set to 2 for LOS and 4 for NLOS, but the difference between two values is usually reduced for IEEE 802.16 relay system evaluation (e.g. [17]). The path between BS and RS is assumed to be in the LOS and the other paths are in the NLOS [9].

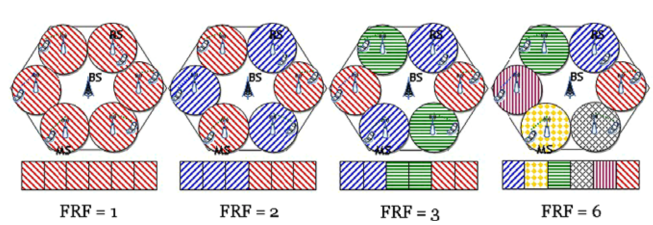

Fig. 2. Frequency reuse patterns.