Resource management policies for fixed relays in cellular networks

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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 802.16f 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 pre-configured relaying channel selection algorithm is proposed. It exploits the channel reuse in a controlled manner to prevent the
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 ampli-
fy-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 desti-
nation 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 elab-
orate 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 out-
age even at the cell boundary where the received signal strength
from the BS is too weak. However, there is a drawback of using re-
lays. 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 con-
sider 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 de-
scribes the system model and Section 3 discusses RRM policies.
Section 4 presents a Monte Carlo simulation algorithm and simula-
tion 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 in-
ter-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.

However, there is a critical difference between the legacy cellular
system and the system where the BS acts like an RS in FTT2. The dis-
tance between an RS and a neighboring RS or the BS may vary in real-
ity 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 exam-
pies 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 inter-
f ered 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 ex-
press the received power $P$ at distance $d$ from the transmitter as

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

where $P_0$ is the received power at distance $d_0$. The path loss expo-
nent $\gamma$ 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, $\gamma$ is set to 2 for LOS and
4 for NLOS, but the difference between two values is usually re-
suced 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].
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