Resource management policies for fixed relays in cellular networks

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A B S T R A C T
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.

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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 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 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.

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 BS 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 BS can transmit downlink traffic to an MS within the BS’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 RSs’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

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

(1)

where $P_0$ is the received power at distance $d_0$. The path loss exponent $\gamma$ 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 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].
Given the signal-to-noise plus interference ratio (SINR) and Shannon formula, we calculate the channel capacity that gives an optimistic performance value. The noise term includes the co-channel interference from other cells and other RSs in the same cell. As the formula gives some channel gain even with a slight SINR gain, there exists some gap between theory and real cellular systems. An alternative way to get the channel capacity is to use the modulation and coding selection (MCS) table for the given system that returns a discrete rate value according to the SINR level.

2.3. Area spectral efficiency

In [16], the average area spectral efficiency (AASE) is defined as the obtainable maximum average data rate per unit bandwidth per unit area for a specific BER. The AASE shows the trade-off between a cellular system’s spectral efficiency and users’ link spectral efficiency. To obtain a user’s high link spectral efficiency, it is required to increase the frequency reuse distance which results in a system’s low spectral efficiency. Assuming TDMA system, the AASE, \( \bar{A}_e \), can be written as

\[
\bar{A}_e = \frac{\mathcal{T}}{\pi W (D/2)^2},
\]

where \( D \) is the distance between two BSs that use the same set of frequencies, \( W \) is the total allocated bandwidth in Hz per cell, and \( \mathcal{T} \) is the maximum average data rate of a user in bps which depends on the user’s SINR. Using the Shannon formula, \( \mathcal{T} \) can be expressed as

\[
\mathcal{T} = W \int_0^\infty \log_2(1 + \gamma) p(\gamma) d\gamma,
\]

where \( \gamma \) is the user’s SINR based on the receiver channel side information (CSI) and \( p(\gamma) \) is the probability density function (PDF) of \( \gamma \).

In our system model, the frequency reuse distance changes between FFT1 and FFT2. Therefore, instead of calculating \( \bar{A}_e \) directly, we calculate the average spectral efficiency within a cell first. Then we calculate \( \bar{A}_e \), assuming \( D \) equals the diameter of the cell because the frequency reuse factor between BSs is one. For the cellular system with fixed relays, we need to use a carefully defined cell spectral efficiency (CSE) metric in calculating \( \mathcal{T}/W \). For a user selecting the direct path, we express the user’s BS-to-MS link spectral efficiency as \( \text{CSE}_{\text{dir}} \). If the relay path is selected, the same resource can be reused up to 6/FRF times more within a cell coverage in case of FFT2, so a new metric \( \text{CSE}_{\text{rel}} \) needs to take this into account. Using these metrics, we can express \( \bar{A}_e \) as

\[
\bar{A}_e = \frac{\text{CSE}_{\text{dir}} \cdot p_{\text{dir}} + \text{CSE}_{\text{rel}} \cdot p_{\text{pre}}} {\pi (D/2)^2},
\]

where \( \text{CSE}_{\text{dir}} \) and \( \text{CSE}_{\text{rel}} \) are the average cell spectral efficiencies for users which select direct path and relay path, respectively, calculated from the PDF of users’ SINR, \( p_{\text{dir}} \) and \( p_{\text{pre}} \) are the probabilities of selecting direct path and relay path respectively, assuming the PDF of user distribution is given. In Section 4, we develop a Monte Carlo simulation algorithm that calculates the average cell throughput which helps us to obtain the AASE.

3. RRM policies

In this section, we discuss RRM policies that can be applied for a cellular network with fixed RSs, and consider some combinations of these policies. Table 1 shows the eight possible combinations for our simulations.

<table>
<thead>
<tr>
<th>Scenario no.</th>
<th>PSR</th>
<th>FRF pattern matching</th>
<th>FTT pattern matching</th>
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<tbody>
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<td>FPSR</td>
<td>MFR</td>
<td>MFT</td>
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<tr>
<td>2</td>
<td>FPSR</td>
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<td>IFR</td>
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<td>6</td>
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<td>FPSR</td>
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<tr>
<td>8</td>
<td>FPSR</td>
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</table>

3.1. Path selection rule

Before an MS starts communication, it should be allocated for a communication path, either the direct path or a two-hop (or relay) path. The selection can be decided by either BS, RS or MS. Since the details of the selection algorithm are out of the scope of this paper, we will briefly mention some practical issues on the selection algorithm in Section 5. Assuming that the decision process considers each MS’s location within the sector, we can consider two PSRs: legacy PSR (LPSR) [15] and proposed FRF-based PSR (FPSR).

To evaluate the spectral efficiencies of the direct path and the relay path, denoted as \( \text{SE}_{\text{dir}} \) and \( \text{SE}_{\text{pre}} \), respectively, we use the channel states of BS-to-RS link (\( \text{SINR}_{\text{BS}} \)), BS-to-MS link (\( \text{SINR}_{\text{BS}} \)), and RS-to-MS link (\( \text{SINR}_{\text{RS}} \)). Then the spectral efficiencies can be expressed as

\[
\text{C}_{\text{BS}} = \text{C}(\text{SINR}_{\text{BS}}),
\]

\[
\text{C}_{\text{BS}} = \text{C}(\text{SINR}_{\text{BS}}),
\]

\[
\text{SE}_{\text{dir}} = \text{C}(\text{SINR}_{\text{BS}}),
\]

\[
\text{SE}_{\text{pre}} = \left( \frac{1}{\text{C}_{\text{BS}}} + \frac{1}{\text{C}_{\text{RS}}} \right)^{-1},
\]

where \( \text{C}_{\text{BS}} \) and \( \text{C}_{\text{RS}} \) are the capacity of BS-to-RS link and RS-to-MS link, respectively, and \( \text{C}(\cdot) \) is a mapping function between SINR and spectral efficiency.

The LPSR works as follows. If \( \text{SE}_{\text{dir}} \geq \text{SE}_{\text{pre}} \), the direct path is selected. Otherwise the relay path is selected. The LPSR just focuses on one MS’s achievable spectral efficiency. The calculation of \( \text{SE}_{\text{dir}} \) does not take into account that the same frequency resource may be reused in the RS-to-MS hop of relay path.

To calculate the spectral efficiency that the BS achieves, we first obtain \( \text{CSE}_{\text{dir}} \) as follows. For simple analysis, we assume that the scheduler can find six RS-MS pairs of the same MCS level within the cell and schedule them at the same time. Fig. 3 shows the case of \( \text{FRF} = 3 \). If an MS is served through the relay path with one unit resource, the portions of used resources at BS-to-RS link (\( \text{W}_{\text{BS}} \)) and RS-to-MS link (\( \text{W}_{\text{RS}} \)), respectively, are given by

![Fig. 3. Example of resource allocation for relaying with FRF 3.](image-url)
The throughput of an MS, $R_{MS}$, is then calculated as

$$R_{MS} = C_{RM}W_{RM} = C_{RM}(FRF \cdot CRM) = \frac{C_{RM} \cdot CRM}{FRF + CRM}. \quad (11)$$

For BS-to-RS link, the BS should assign different resource to each RS. The sum of used resources for six BS-to-RS transmissions is $6 \cdot W_{RM}$. Since the six RSs can reuse the same resource 6 times, the total resources $B_{IRS}$ used by six MSs through the relay path are given by

$$B_{IRS} = 6 \cdot W_{RM} + FRF \cdot CRM = 6 \cdot CRM + \frac{FRF \cdot CRM}{FRF + CRM}. \quad (12)$$

Then we obtain the average spectral efficiency of six MSs ($SE_{avg}$) as

$$SE_{avg} = \frac{6 \cdot R_{MS}}{B_{IRS}} = \frac{6 \cdot CRM}{6 \cdot CRM + FRF \cdot CRM} \cdot \left(1 + \frac{FRF}{6 \cdot CRM}\right)^{-1}. \quad (13)$$

and name it $CSE_{avg}$.

The FPSR runs as follows. If $SE_{dir} \geq CSE_{avg}$, the direct path is selected. Otherwise the relay path is selected. The FPSR rule considers that the same frequency can be reused by up to 6 times within the cell and a BS can achieve higher spectral efficiency at the possible cost of slightly lowered some MSs’ spectral efficiencies. To obtain high $CSE_{avg}$, the resources should be fully reused. Otherwise the actual cell throughput can be reduced.

Fig. 4 shows an example that different PSRs result in different path selection. In this example, the BS wants to transmit packets to the MS. Let us assume that the capacity of each link and the packet size ($B$) are given as follows.

$$CBR_{RM} = 10, \quad CRM_{RM} = 12, \quad CRM_{BH} = 40, \quad B = 40. \quad (14)$$

When the LPSR is applied, the amounts of needed resources are calculated for direct and relay paths, respectively, in the MS’s point of view. The amount of resource needed in the direct path is 4. That in the relay path is calculated as follows. In FTT1, the BS-to-RS transmission requires 3.3 resources while the RS-to-MS transmission needs one resource in FTT2. In total, 4.3 resources are needed for the relay path. So the direct path is chosen in LPSR.

However, in the BS’s point of view, the total amount of resource needed for multiple packet transmissions is not the sum of the amount of resource for each transmission because the same resource can be reused for multiple RS-to-MS transmissions according to the FRF applied. In case of FRF = 3, two RS-MS pairs can be scheduled for the same resource in FTT2. If these two MSs are served by the direct path, the total of eight resources are needed. On the other hand, if the relay path is selected, 6.7 resources are needed for the two BS-to-RS transmissions in FTT1 and one resource is needed for the two simultaneous RS-to-MS transmissions in FTT2. In total, 7.7 resources are necessary to serve two MSs. So the relay path will be selected in FPSR.

### 3.2. Frequency reuse and frame transmission pattern matchings among cells

To exploit an optimal frequency reuse pattern among RSs, it is appropriate for the all cells to use the same reuse pattern among RSs. This policy is named matched frequency reuse pattern among cells (MFR). However, if such coordination is not possible, each cell needs to choose a reuse pattern independently, and we name it independent frequency reuse pattern among cells (IFR). The IFR can practically handle the case that each cell is with different loading for each logical sector.

The interference at each MS is affected by not only FRF but also FTT of neighboring cells. The policy that all the cells have the same FTT is called matched frame transmission pattern among cells (MFT). If each BS schedules the FTT according to the buffered data size and required QoS independently, we call it independent frame transmission pattern among cells (IFT).

### 4. Monte Carlo simulation and results

For simulations, we consider the downlink of a cellular system with fixed RSs and compare cell throughput and outage ratio for each RRM scenario shown in Table 1. The outage ratio is defined as the fraction of MSs that cannot receive any service due to their poor channel conditions. Cell throughput comparison is performed by locating a certain number of MSs within the cell randomly following the PDF of each MS’s position and adding each MS’s spectral efficiency over the selected path. However, as $SE_{avg}$ does not take into account that the resource can be reused by up to 6 times more at RS-to-Ms link, we are not able to compare each case fairly.

This motivates us to develop a Monte Carlo simulation algorithm. Our algorithm consists of four steps and considers the CSE of the relay path well. Note that the scheduler can find six RS-Ms
Fig. 5. Cell throughput.

pairs in a cell using the same MCS level and schedule them at the same time; then our algorithm is given as follows.

1. Locate an MS randomly within a sector according to the PDF of user distribution.
2. Calculate the SINR of each link and the spectral efficiency of each path, and choose a path according to the PSR given in Section 3.1.
3. Calculate total cell throughput and the total used resource for the six MSs.
   - If the relay path is selected, the cell throughput is \(6 \cdot R_{\text{MS}}\) and the total used resource is \(B_{\text{MS}}\).
   - If the direct path is selected, the cell throughput is \(6 \cdot S_{\text{dir}}\) and the total used resource is 6.
4. Repeat 1, 2 and 3 until the total used resource reaches a given threshold, and calculate the sum of cell throughput.

We performed Monte Carlo simulations for eight simulation scenarios shown in Table 1. In each scenario, we compare the performances of different FRFs according to \(R\). To obtain the lowest performance bound, a legacy cellular system without RSs was also simulated. For the considered topology of 19 cells, we evaluated the cell throughput in the downlink and the outage ratio at the center cell.

Two-tier surrounding cells are used to generate the interference. The radius of each cell is 1000 m. The ratio of the transmission power of BS to that of RS is 2. Antennas are omnidirectional. Ignoring the inter-frequency interference, we use the MCS table of IEEE 802.16e Korean version (WiBro) system given in Table 2.

The system is assumed to be fully loaded. The location of each MS follows the uniform distribution within a logical sector. At interfering cells, FRFs in case of IFR and FTTs in case of IFT are selected independently and randomly with equal probability. Each simulation was executed for 20,000 frame time. Fig. 5 shows the cell throughput for each scenario and Fig. 6 shows the outage ratio. The AASE can be calculated by dividing the cell throughput by the number of transmitted frames and the area.

To investigate the impact of the PSR, we compare scenarios 2i–1 and 2i (i = 1, 2, 3, 4). Its impact on the performance of cell throughput depends on FRF. When we changed the PSR from FPSR to LPSR, we observed a significant throughput degradation in the case of \(FRF = 1\). As \(FRF\) increases, the reduced amount becomes less noticeable. Therefore we prefer FPSR to LPSR. For outage ratio, the PSR doesn’t affect the performance at all. This is because if an MS is in outage, both direct and relay paths have zero capacity. So \(S_{\text{tot}}\) and \(C_{\text{rel}}\) do not make any difference in performance and there is no performance gap between the two PSRs.

The comparison between scenarios \(i\) and \(i + 4\) (\(i = 1, 2, 3, 4\)) reveals the effect of frequency reuse pattern matching. The total cell throughput depends on \(FRF\) as expected, but the tendency is opposite to that of the above observation. When we tried IFR, we observed a significant throughput degradation in the case of \(FRF = 6\) against \(FRF = 1\). The outage ratio decreases as the \(FRF\) increases in MFR. However, in IFR, \(FRF\) does not affect that much in outage ratio. This is because the intercell interference generated by random and uncoordinated frequency reuse pattern heavily influences the SIR of an MS near the cell boundary, regardless of \(FRF\) at the center cell.

Now we compare scenarios \(i\) and \(i + 2\) (\(i = 1, 2, 5, 6\)) to observe the influence of frame transmission pattern matching. We could not find a clear relationship between MFT and cell throughput. In some cases, the point where maximum throughput is observed varies. When we tried IFT, we obtained different forms of outage ratio curve. The performances for \(FRF = 1\) and 2 seem to be more influenced by MFT than those for \(FRF = 3\) and 6.

![Fig. 6. Outage ratio.](image-url)
Fig. 7 shows the PDF and cumulative distribution function (CDF) of each MS’s spectral efficiency in scenarios 1 and 2. In cases of FRF = 6 and no RS, the results are identical in scenarios 1 and 2. In each PDF graph, the bar at MCS level $m$ shows the percentage of MSs whose spectral efficiency lies between those of MCS levels $m-1$ and $m$. If $m = 0$, the outage occurs. The white bar indicates
the percentage of MSs that are served by the relay path and the black bar the percentage of MSs served by the direct path. As FRF becomes larger, the PDF shifts to the right, and the relay path serves more MSs than the direct path does. The CDF graph shows performance variation according to the FRF more clearly. However, these graphs do not show how many MSs can be served for a fixed number of frames. The PSR does not change the shape of PDF much, but the larger portion of the white bar in scenario 1 indicates that FPSR selects the relay path more often than LPSR does. From Table 3, we notice that there exists a tradeoff between the number of MSs that can be supported within the cell and the average spectral efficiency that an MS can achieve. Especially for FRF 1 and 2, scenario 1 serves more users than scenario 2 because the same frequency resources can be reused when the relay path is selected.

Comparing all the scenarios, we obtain some guidelines for choosing the parameter values that give best performance in terms of throughput and outage ratio. In most cases, the optimal R is 600 m, which gives low outage ratio and high cell throughput. The maximum acceptable outage ratio affects the choice of FRF very much. If more than 10% of outage is acceptable, FRF 1 achieves highest throughput. However, as a common objective is to provide a certain level of fairness to users at the cell boundary, lowering the outage ratio at the boundary is necessary, which can be achieved by deploying RSs. Considering these together, FRF 3 is a reasonable choice which achieves the outage ratio of less than 2% and 90% of the maximum throughput. In case of IFR, the outage ratio is about the same regardless of FRF. This means that FRF 1 shows the best performance. If most of the cells choose FRF 1 to achieve high throughput, the IFR becomes similar to MFR. So the performance gain will decrease.

5. Consideration of practical issues

In this section, we consider some practical issues for deployment. When we apply the PSR, we need to have the channel capacity first. Assuming the channel reciprocity, only the downlink channel capacity is in need. After the path selection, the system may require both the downlink and uplink channel capacity for bidirectional data transmission. To help this, the BS transmits a pilot signal and each RS estimates BS-to-RS link quality and transmits a pilot signal for each MS. Each MS estimates BS-to-RS link quality and BS-to-MS link quality to the BS and each MS sends BS-to-RS and BS-to-MS link qualities to the BS. In case of MS running the PSR, only BS-to-RS link information is sent to the MS. When an RS transmits a pilot signal, it broadcasts BS-to-RS link information. So, in terms of the signaling overhead, MS running case performs better than BS running case. The simulation results show that FPSR always performs better than LPSR. However, in FPSR, we need the assumption that the scheduler can always find an RS-MS pair in each sector using the same frequency band and the same MCS level. This assumption is not practical in real systems, so the performance gap between FPSR and LPSR will decrease. Also when each MS runs the FPSR, it should know the FRF value first, which can be broadcast by the BS. However, due to the geographical irregularity, the positions of RSs are most likely asymmetrical. Therefore the BS needs to estimate the FRF value approximately by considering the resource allocation and scheduling information. As the estimated FRF value may vary depending on the position of each MS, it may incur too much overhead for BS to estimate an accurate FRF value for each MS.

6. Conclusion

In this paper, we considered a cellular network with fixed RSs which is designed to provide fair spectral efficiency for MSs near the cell boundary. In the considered relay supported network, a cell boundary user can transmit data packets towards the BS over either the direct path or the relay path. For path selection, we considered various resource management policies that include path selection rules, frequency reuse pattern, and frame transmission pattern among cells. To evaluate each policy, we performed a Monte Carlo simulation with varying system parameters such as frequency reuse factor and the distance between BS and RS. Simulation results gave us an insight for choosing appropriate RRM policies and system parameters. Also we found that the path selection rule in FPSR performs better than that in LPSR. In most cases, an optimal R was 600 m. If the outage ratio of greater than 10% is acceptable, FRF 1 can be a good choice to achieve high throughput. Otherwise FRF 1 and 3 are the best choices in the cases of independent frequency reuse factor and matched frequency reuse pattern, respectively. There are some issues to be considered when relays are deployed in the cellular system. The signaling overhead for channel quality feedback depends on which device selects the path for communication. Also estimating the FRF value may be difficult and the signaling overhead may be large in real cellular systems due to the irregular and asymmetric relay deployment.

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References


