

Analyzing the impact of relay station characteristics on uplink performance in cellular networks

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Abstract. Uplink users in cellular networks, such as UMTS/ HSPA, located at the edge of the cell generally suffer from poor channel conditions. Deploying intermediate relay nodes is seen as a promising approach towards extending cell coverage. This paper focuses on the role of packet scheduling in cellular networks with relay nodes. In particular, two uplink scheduling schemes deploying the relay functionality in different ways are compared in performance to a reference scenario where relaying is not used. We derive expressions which characterize for each of the two relay-enabled schedulers the service area of a relay station as a function of the relay location and transmit power. The results show that the service area is significantly influenced by the type of scheduling. Examining for both schedulers the impact on the effective data rates of mobile stations shows that there is an optimal combination of relay's position and transmit power which maximizes the service provided to all mobiles.

1 Introduction

Nowadays, a healthily functioning society is hardly imaginable without widely accessible and well operating communication networks. The tendency is towards wireless technologies providing high data rates and wide coverage. Pervasive wireless coverage, both indoors and outdoors, is hindered by the construction landscape of the area. An elegant way to improve performance in poor coverage area is to position a relay station (RS). A relay breaks up a direct communication path into two indirect paths. Given a well chosen position of the RS, indirect paths can provide better channel conditions than direct paths. In addition, relaying can be incorporated on both downlink, from base station (BS) to mobile station (MS), and uplink, from MS to BS. The application of relaying for coverage improvement has been studied for a broad range of wireless technologies, including WiMAX, see [10, 2], and cellular networks, see [9, 8, 12].

We propose a broader use of relaying, namely, to enhance offered service in general. In our proposal a mobile station, even if located in an area with coverage, can choose to use a relay if this improves its effective data rates. This paper is based on the EUL (Enhanced Uplink) technology which is described in the 3GPP Release 6 of the UMTS (Universal Mobile Telecommunications System) standard, see [1]. However, our approach has the potential to extend towards other cellular systems such as LTE technology, which is currently under standardization. Being the latest cellular technology

with high implementation percentage in Europe and North America and growing on other continents, UMTS/EUL is a good candidate to show the benefits of relaying for operators and mobile users.

The idea of relaying is rather attractive, however its implementation is not trivial. Placing a relay station within the cell poses new deployment decisions such as where to set the relay or how many do we need. In order to select the optimal solution we need to investigate how these decisions influence performance of the mobile stations. For example, [12] elaborates on the density of relays for the downlink in beyond-3G networks. Most importantly, the area over which a relay can improve performance, i.e. service area, has to be established.

An additional factor which influences the use of relays is the scheduling scheme at the base station. In order to understand why scheduling is relevant, we need to be familiar with certain features of EUL. In EUL the key resource is the maximum acceptable power received at the base station. The available channel resource is shared among all active users as the channel access is organized by the base station (BS) via time frames with fixed length, 2 or 10 ms, termed TTI (Transmission Time Interval). Furthermore, depending on location, a MS's transmit capacity may be insufficient to utilize the available resource, in which case diversity of scheduling schemes become an attractive choice. Several studies, for example [7, 3, 4], dedicated to scheduling in the EUL, show that the choice of scheme has a major impact on performance.

Our goal in this paper is to evaluate the performance of MSs under the combined influence of crucial relay characteristics and the type of scheduling at the BS. In particular, we are interested in finding optimal relay location and transmit power, which maximize the overall performance. Two relay-enabled scheduling schemes are proposed and investigated. For each scheme the mobile stations' performance at different locations is evaluated in terms of effective data rates. In addition we derive explicit analytical expressions to determine the relay's service area, which are subsequently supported by simulations.

Our work is related to [6] which discusses similar relay configurations for HSDPA. Although insightful, [6] does not provide any analytical derivations. On the contrary, [11] provides a very detailed cross-level analysis of relaying but does not consider the impact of particular scheduling schemes and other system characteristics. In summary, the most prominent contributions of our research are: discussion on the uplink of a cellular system; analytically defining the boundaries of a service area; and combined assessment based on both scheduling and RS specifics.

The paper continues as follows. First, in Section 2, we briefly discuss the relaying concept and describe the scheduling schemes considered in this paper. The model description and analysis appear in Section 3 and Section 4, respectively. Section 5 presents our findings of the performance evaluation. Finally, Section 6 summarizes our work.

2 Relay-enabled Round Robin Scheduling Schemes

We would first discuss how relaying can be applied in a cellular system and will introduce relevant notation. Next, the scheduling schemes considered in this paper are described.

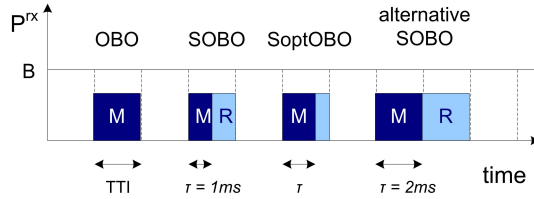


Fig. 1. Scheduling schemes: OBO, SOBO, SoptOBO, SidOBO and ExOBO

Relaying artificially breaks up a long communication path into two shorter ones. As result signal degradation decreases and received powers at the BS improve. These gains are partly lost to increased transmission time from the additional forwarding of data at the relay node. Thus, whether a relay can improve performance does not have a simple answer. In order to choose between an indirect path (MS-RS-BS) and a direct path (MS-BS) we need to evaluate the data rates realized on both. In a relay-enabled system the data of a MS which selects for the relay travels over two sub-paths, MS-RS and RS-BS, and the effective data rate on the indirect path depends on the data rates realized on the two sub-paths.

Each (sub-)path is characterized by a set of transmission parameters: the distance between the communicating devices d_{zz} , the path loss L_{zz} , the transmit power P_{zz}^x , the duration of a transmission opportunity τ_{zz} and the instantaneous data rate r_{zz} during a transmission opportunity. The index zz refers to the specific (sub-)path, i.e. ms for the direct path from MS to BS, mr for the sub-path from MS to RS, and rs for the sub-path from RS to BS. The transmission times τ_{mr} and τ_{rs} are scheduler specific; their sum is denoted by $\tau = \tau_{mr} + \tau_{rs}$. Any further relations between the transmission parameters are discussed in Section 4. We now continue with introducing the scheduling schemes considered in our study.

Scheduling Schemes

The discussed schedulers belong to the Round Robin (RR) family where mobile users are served one-by-one (OBO), independently of their channel conditions. According to several studies, for example [7, 5], OBO is a rather inefficient in resource utilization if users with limited power capacity are served. Still we choose OBO since we expect relaying to increase the capability of a MS to fully use the available resource. In our study we consider two variants of a relay-aware OBO scheduler: *SOBO* and *SoptOBO*. A MS can select the direct or the relay path, depending on its location relative to the BS and the RS. In addition, plain *OBO* is considered as a reference scheme in which a MS always transmits directly to the base station independently of its location in the cell. All schemes assign a single TTI for the transmissions on direct and indirect paths, i.e. $\tau = 2ms$.

On the indirect path, a *shared OBO* (SOBO) scheme divides the TTI into two equal intervals of $1ms$ and MS and RS both receive one interval to transmit, i.e. $\tau_{mr} = \tau_{rs} = 1ms$. The benefits of working with fixed-length transmission times for direct and indirect paths exhibit during implementation. However, static subdivision for indirect paths is not the most efficient choice when the instantaneous rates on the sub-paths differ.

Apart from SOBO, various other schemes which apply fixed-length transmission times can be defined. For example, using a single TTI for the transmissions on both sub-paths, i.e. $\tau_{mr} = \tau_{rs} = 2ms$, meaning the BS reserves 2 TTIs for the service of a single MS. It can be shown that all schemes which, independently of precise values, use equal division of τ , i.e. $\tau_{mr} = \tau_{rs}$ have the same effective data rates. Therefore, we can claim that SOBO is representative for a group of schedulers.

In the *Optimized SOBO* (SoptOBO) the channel utilization for indirect paths is optimized by selecting the transmission times on the sub-paths such that both sub-paths MS-RS and RS-BS match in transmission capacity, i.e. $\tau_{mr}r_{mr} = \tau_{rs}r_{rs}$. Despite its maximized resource utilization SoptOBO is rather challenging for implementation since individually selecting transmission times for the sub-paths requires complex functionality in the base station.

3 Model

The model we consider consists of a single cell with EUL users (MSs) at random locations within the cell. A MS selects a direct or indirect path depending on which one provides higher effective data rate/ received power. Which parameter is used is a scenario specific choice and is explicitly indicated. All mobile stations are assumed to have the same maximum transmit power capacity $P_{ms,max}^{tx}$. The maximum transmit power of the RS is $P_{rs,max}^{tx}$. However, depending on location and the available budget B , MS/RS use either the maximum transmit power or a lower power, i.e. $P_{zz}^{tx} \leq P_{zz,max}^{tx}$ ³. The actually applied transmit power is chosen such that a MS maximizes its utilization of the budget B .

Given that we want to calculate the service area of a relay, we consider a cell with a single relay station. The service area is the aggregation of all locations within the cell from which a MS receives better service via the relay station. In addition, we are interested how the relay position and transmit power influence MS performance. Their impact is evaluated by both mathematical expressions and Monte Carlo simulations. We assume that a RS use the same frequency band for receiving and transmitting and that the change of mode is instantaneous.

At both BS and RS limited channel resource, budget B , is assumed. Given noise rise η and constant thermal noise N , the shared budget B at the BS, and RS, is derived: $B = \eta N$. Intentionally disregarding important factors such as inter- and intra-cell interference allows us to identify the effect relaying has on performance. However, we realize that such factors may have significant effects on the performance gains.

4 Analysis

In this section we concentrate on two distinctive aspects of relaying - the service area of the relay station and its impact on MS performance. Relaying has two opposite effects on mobile stations. On the one hand higher received powers are enabled (increasing the effective data rate), but on the other hand forwarding at the RS requires an additional

³ Note that $P_{ms,max}^{tx} = P_{mr,max}^{tx}$.

transmission of the data (decreasing the effective data rates). For each scheduler we start with calculating the received powers from which subsequently data rates can be derived.

According to its definition the service area is the collection of locations from which the indirect path is preferred. Depending on the selection criteria we differentiate between service area based on received powers and based on effective data rates. For both cases, we derive generic expressions which allow us to calculate the service area as a function of the RS's position and transmit power.

4.1 Received Powers from Mobile Stations

According to signal propagation law, the received power P_{zz}^{rx} on any communication path is determined by the applied transmit power $P_{zz}^{tx} \leq P_{max}^{tx}$ and the path loss $L_{zz}(d)$. The maximum possible received power on an EUL path is limited by the available budget B at the receiver leading to:

$$P_{zz}^{rx} = \min\left(\frac{P_{zz,max}^{tx}}{L_{zz}(d)}, B\right) \quad (1)$$

where the index $zz=(ms, mr, rs)$ denotes the (sub-)path over which the transmission is done. The assumed path loss model is given by $L(d) = 123.2 + 10a \log_{10}(d)$ (in dB) with $a = 3.52$ the path loss exponent and d the distance in kilometer.

Note that in SOBO the received powers at the base and relay station are the same since the indirect path transmission is limited by the slower sub-path. In SoptOBO however, according the definition, generally these two received powers are different, as the unbalance in received powers is compensated for by difference in transmission time, see Section 2.

4.2 Effective Data Rates

The data rate achievable on a (sub-)path zz given a particular transmit power capacity is the *instantaneous rate* r_{zz} . Its dependency on other transmission parameters is given by:

$$r_{zz} = \frac{r_{chip}}{E_b/N_0} \cdot \frac{P_{zz}^{rx}}{N + (1 - \omega)P_{zz}^{rx}} \quad (2)$$

In Equation (2) r_{chip} is the system chip rate and E_b/N_0 is the energy-per-bit to noise ratio. The parameter ω is used to account for reflected signals and the index $zz = (ms, mr, rs)$ refers to the (sub-)path. The maximum possible data rate a MS can realize is determined by the condition that the budget B can be filled, i.e. $P_{zz}^{rx} = B$.

The *effective rate* r_{eff} is the rate realized by a MS during the transmission opportunity τ . On the direct path, indexed ms , the effective rate is the same as the instantaneous, i.e. $r_{eff} = r_{ms}$, because the whole τ is used by the MS. On the indirect path however, due to data forwarding, the effective rate is lower than the instantaneous. r_{eff} depends on the part of τ used by the mobile, i.e. on τ_{mr} , and on the instantaneous rate that the MS can realize during τ_{mr} . In SOBO $\tau_{mr} = \tau/2$ while in SoptOBO $0 < \tau_{mr} < \tau$ depending

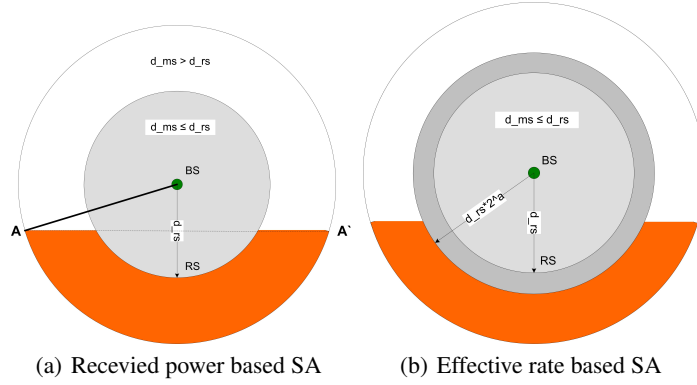


Fig. 2. Service area (SA) of a single relay station based on: (a) received power levels; and (b) effective data rates.

on MS location such that $r_{mr}\tau_{mr} = r_{rs}\tau_{rs}$ and $\tau_{mr} + \tau_{rs} = \tau$. Given the scheduler specific time assignment policy the expression of the effective rate becomes:

$$r_{eff} = \begin{cases} r_{ms} & \text{for OBO and direct path in SOBO\&SoptOBO} \\ \min(r_{mr}, r_{rs}) * \frac{1}{2} & \text{for indirect path in SOBO} \\ \frac{r_{mr}\tau_{mr}}{\tau} & \text{for indirect path in SoptOBO} \end{cases} \quad (3)$$

4.3 Service area of a relay station

Our goal in this sub-section is to analytically determine the critical distance d_c at which a MSs changes its preference from direct to indirect path and which determines the boundaries of the service area. We will show that the shape and surface of the service area depend on whether received powers or effective data rates are used in the analysis. As we showed in Section 4.2, due to data forwarding the gains in effective rates are lower than what received powers 'promise'. Therefore, it is more appropriate to calculate service area based on effective rates. However, working with received powers provides us with a good reference base to illustrate our claim.

Service Area Based on Received Powers

In this scenario, a mobile station selects the transmission path - direct or indirect - which can offer higher received power at the base station. Recall that in SOBO the received power for the indirect path is determined by the sub-path with poorer channel conditions. The condition to select indirect transmission can be written as:

$$P_{ms}^{rx} < \min(P_{mr}^{rx}, P_{rs}^{rx}) \quad (4)$$

From Equation (1), assuming the same transmit power for MS and RS, we can deduce that the received power is only dependent on the distance between the communicating stations. Therefore, the condition from Equation (4) can be rewritten as:

$$d_{ms} > \max(d_{mr}, d_{rs}) \quad (5)$$

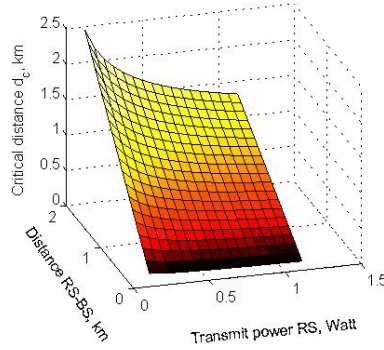


Fig. 3. Dependency of the critical distance on both distance of relay to the base station and the transmit power of the relay for a SOBO scheme.

We will now explain how Equation (5) can be transformed to a spatial limitations in the cell. A circle with radius d_{rs} around the base station can be drawn, see Figure 2(a), within which $d_{ms} \leq d_{rs}$ holds and a MS always selects the direct path; outside it - the indirect is preferred. The single relay station in our model is not sufficient to cover the whole disc for which $d_{ms} > d_{rs}$ is valid. However, by applying basic geometry rules for medians we can find the line AA', see Figure 2(a), all points of which have the same distance to the base station as well as to the relay. All MSs 'below' AA' have $d_{ms} > d_{mr}$ and can benefit from relaying. The intersection of the two inequalities defines the relay's service area.

Service Area Based on Effective Data Rates

In order to keep calculations tractable, yet providing useful insights, we consider the scenario when BS, RS and MS lay on a straight line. Both schemes - SOBO and SoptOBO - are discussed as we provide analytical expressions to find the critical distance. We begin with discussion on SOBO. A MS always selects the path, i.e. direct or indirect, which provides higher effective data rate. The critical distance d_c is then the distance d_{ms} for which direct and indirect paths realize the same effective rate. According to Equation (3), the condition can be formally expressed as:

$$r_{ms} = \min(r_{mr}, r_{rs}) * \frac{1}{2} \quad (6)$$

Note that, given a straight line BS-RS-MS, when $d_{mr} > d_{rs}$ holds by default indirect transmission is chosen. Substituting with Equations (2) and (1) and solving for d_{ms} , we can derive a formal expression for d_c , namely:

$$d_c = d_{rs} * \left(2 \frac{P_{ms,max}^{tx}}{P_{rs,max}^{tx}} \right)^{1/a} \quad (7)$$

This general expression takes both characteristics of the relay - transmit power P_{rs}^{tx} and position d_{rs} - as parameters; a is the path loss exponent. The dependency is graphically presented in Figure 4.3. When RS have the same transmit capacity as of a mobile

the equations reduces to $d_c = d_{rs} * (2)^{1/a}$. The discussion continues with analysis for SoptOBO. From Equation (3) follows that the critical distance d_c is determined by the equality:

$$r_{ms} = \frac{r_{mr} \tau_{mr}}{\tau} \quad (8)$$

Per definition SoptOBO is optimized for the transfer of equal amount of data on both sub-paths. In combination with the limitations set on the transfer times, that knowledge allows us to express τ_{mr} in terms of rates, namely:

$$\begin{aligned} r_{mr} \tau_{mr} &= r_{rs} \tau_{rs} \\ \tau_{mr} + \tau_{rs} &= \tau \quad \Rightarrow \quad \tau_{mr} = \tau * \frac{r_{rs}}{r_{mr} + r_{rs}} \end{aligned} \quad (9)$$

After several substitutions and solving Equation (8) for d_{ms} , the critical distance can be given as a function of the positions of both, the relay and the mobile station. For a solution dependable only on relay characteristics we need to solve the system of equations:

$$\begin{aligned} d_c &= \left(d_{mr}^a + \frac{P_{ms}^{tx}}{P_{rs}^{tx}} \cdot d_{rs}^a \right)^{1/a} \\ d_c &= d_{mr} + d_{rs} \end{aligned} \quad (10)$$

The system of equations (10) is in general difficult to solve explicitly and we therefore use numerical approaches. Again if we assume the relay to have the same transmit capacity as a mobile station Equation (10) simplifies to $d_c = (d_{mr}^a + d_{rs}^a)^{1/a}$.

5 Numerical results on relaying

This section presents a quantitative evaluation of the impact a relay station has on the performance of mobiles. First, we discuss how key characteristics of the relay such as position and transmit power influence the effective data rates of the MSs, Sections 5.2 and 5.3 respectively. In both cases straight line BS-RS-MS is discussed. Since these are relay and not scheduler related characteristics we present the results only for SOBO. In the rest of the numerical results the relay station is located at 1 km from the BS and has transmit power $P_{rs}^{tx} = 0.125$ Watt, if not otherwise specified.

Subsequently, the service area of a relay station is presented in Section 5.4. We compare the results of Monte Carlo simulations for SOBO and SoptOBO. OBO does not use relaying and is excluded from the discussion. We generate 500 000 locations and for each compare whether direct or indirect path provides higher effective rate.

Finally, the three scheduling schemes - OBO, SOBO and SoptOBO - are compared in terms of effective data rates. The results are generated for 500 000 randomly taken locations of MSs by applying the analytical expressions of Section 4.2. On the hand of spatial graphs we illustrate how relaying can improve performance and what scheduling at the relay is more beneficial.

5.1 Parameter Settings

In the numerical experiments we apply system chip rate r_{chip} of 3840 kchips/s, thermal noise level N of -105.66 dBm and noise rise target η of 6 dB. From the given noise rise

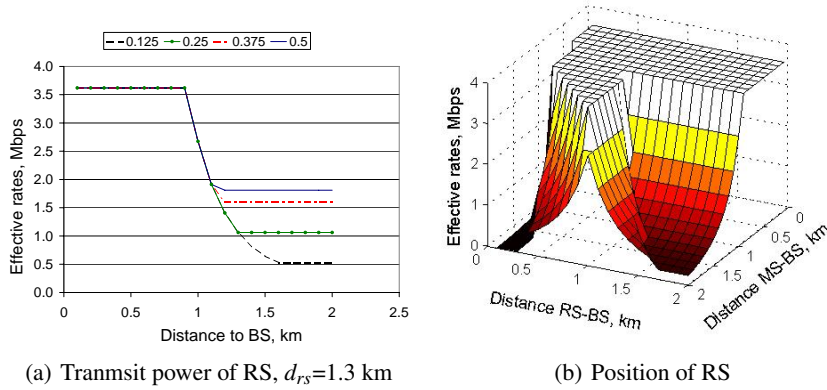


Fig. 4. Impact of RS characteristics on MS performance with SOBO scheduler: (a) RS transmit power; (b) RS position.

and thermal noise the available budget at both BS and RS can be calculated: $B = \eta * N$. Self-interference of 10% is considered, i.e. $\omega = 0.1$. All EUL flows are taken with E_b/N_0 target of 5 dB. By default, a single relay station is located at 1 km from the base station and has P_{rs}^{tx} either 0.125 Watt. Mobile stations have maximum transmit power $P_{max}^{tx} = 0.125$ Watt.

5.2 Transmit Power of the Relay Station

Figure 4(a) presents the results for four different RS transmit powers, namely (0.125 0.25 0.375 0.5) Watt, given the RS is located at 1.3 km from the base station. If the MSs transmit directly to the base station the graphs coincide and the differences start to appear when the relay is used. Interestingly, as the transmit power grows the distance at which indirect transmissions are preferred decreases. Higher RS transmit power leads to better budget utilization - better than a MS closer to the BS but with lower transmit capacity can achieve.

A MS on the direct path realizes the maximum possible effective data rate when it can fully utilize the available budget B , suggesting $P^{tx}(BS) = B$. Given a transmit power, from Equation (1) we can calculate the maximum distance for which $P^{tx}(BS) = B$ holds, namely $d_{ms,max}$. With the chosen parameter settings $d_{ms,max}$ equals 0.9 km, resulting, according to Equation (2), in 3.6 Mbps. As Figure 4(a) shows, 3.6 Mbps is the effective rate for all MSs up to and including 0.9 km after which increasing the distance leads to decrease in the rate.

Given a cell radius of 2 km, the furthest MS is located at 0.7 km from the relay. Thus all indirect transmissions are relay-limited, which explains the flat graphs of Figure 4(a) after relay is used. Under the condition of fully used budget B , i.e. the case of $P_{rs}^{tx} = 0.5$ Watt, the maximum possible effective rate on the indirect path is twice smaller compared to the direct path due to data forwarding, see Equation (3).

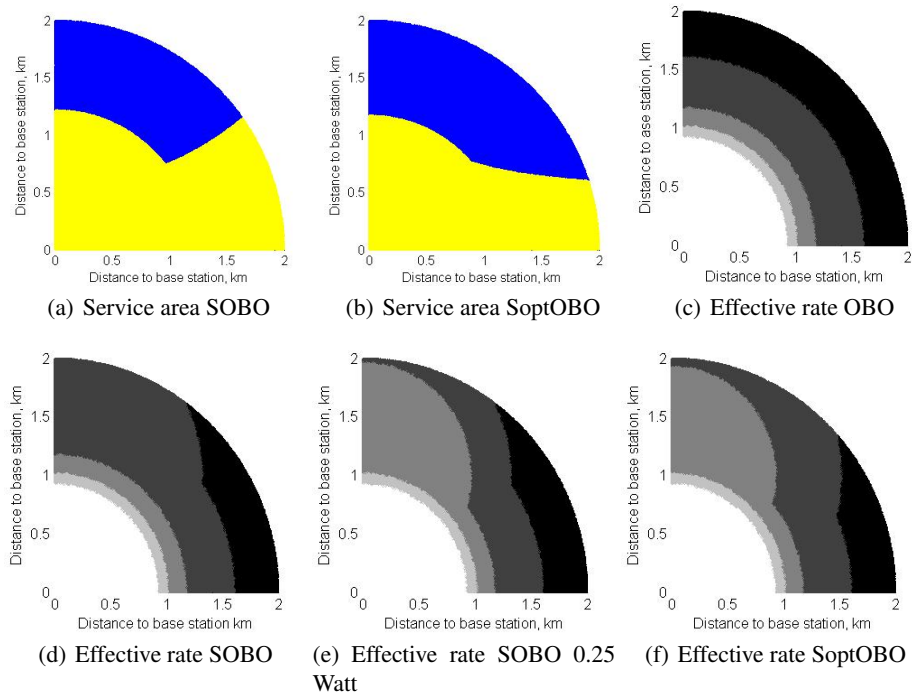


Fig. 5. Spatial behaviour in the cell with a relay station located at 1 km and transmit power 0.125 Watt. Shape of service area for: (a) SOBO and (b) SoptOBO. Effective data rates for: (c) OBO; (d) SOBO; (e) SOBO with RS transmit power 0.25 Watt; and (f) SoptOBO.

5.3 Position of the Relay Station

The three dimensional graph in Figure 4(b) illustrates how the effective data rates change when the location of both mobile and relay station changes. It seems that a RS at 1 km has optimal performance. MSs close to the base station can use the total resource on their own and therefore show the same performance, i.e. flat area. The same holds for the relay station with the exception of remote MSs, e.g. at 1.5 km, whose own distance to the relay limits the performance. Moving the relay further away has a two-fold effect. On the one hand, increased distance to the base station leads to lower effective rates. On the other hand, the number of MSs which can benefit from relaying decreases. Furthermore, not only the number of directly sending MSs increases but their effective rates decrease due to longer distance to the BS.

5.4 Service Area

In this section the service area of a relay station at 1 km from the base station and with transmit power of 0.125 Watt is discussed. The service area is based on effective data rates. The results for SOBO and SoptOBO are presented in Figures 5(a) and 5(b)

respectively, where the dark surface corresponds to the service area, i.e. indirect transmissions, and the light surface - to all locations from which direct transmissions are preferred. The service area for only quarter of the cell is given since the area is symmetrical around the relay. Obviously, MSs from the other half of the cell always choose the direct path.

Comparing Figures 5(a) and 5(b) we can conclude that using SoptOBO extends the area mainly for locations far from the relay while the changes for close ones, i.e. at 1.2 km, are negligible. The bigger the difference in effective rates on the two sub-paths for SOBO, the bigger the improvements SoptOBO can offer. Since the asymmetry is larger for far self-limiting MSs they also gain the most with SoptOBO.

Note that the service area does not start right behind the relay which supports our conclusion from Section 4.3 that the actual service area is smaller than the improvements in received powers may suggest. Solving Equation (10) on the straight line BS-RS-MS for SOBO results in 1.22 km, what Figure 5(a) indicates as well.

Knowing the service area of a relay could assist us in choosing the number of relays to cover the whole outer part of the cell. However, it is more important to observe the effect of relaying on the MSs' performance.

5.5 Effective Data Rates

The spatial distribution of the effective rates for the three schedulers - OBO, SOBO and SoptOBO - is shown in Figures 5(c) to 5(f). In addition, an SOBO scheduler with higher transmit power of the relay is considered. Again a quarter cell is depicted as the brightness changes from high to low as the rates decrease. MSs located in the central white sector with sector around the BS with radius 0.9 km can fully utilize the available budget B . In all scenarios where relaying is used performance visibly improves.

Increasing the RS transmit power, see Figure 5(e), is only beneficial for RS-limited transmissions, which is most commonly the case of MSs close to the relay. Since the relay has the same available budget B as the BS, the same calculations for $d_{ms,max}$ hold, see Section 4.1. Thus explaining the circle with radius 0.9 km around the RS in Figure 5(e).

A relay configuration with SoptOBO scheme delivers better performance and larger service area than a SOBO scheduler offers, see Figure 5(f). Adapting the transmit times according to the MS location gives each mobile the opportunity to improve its effective rate. The improvement depends, as explained, on the instantaneous data rates on the two sub-paths. We do not expect significant changes if the RS transmit is increased with SoptOBO.

6 Conclusion

This paper discussed the benefits that relaying has to offer to mobile users by comparing the performance of two relay-enabled schemes to a reference scheduler with no relay. To analytically describe the service area of a relay we provided two independent approaches - based on received powers at the base station and based on effective data rates. These approaches are supported by simulations. The results show that the

shape and size of the service area depend on the relay characteristics but also on the scheduling schemes. We also evaluate how relay characteristics such as transmit power and location affect the effective rates of the mobiles. Interestingly, there is an optimal relay location, which maximizes the performance for all mobiles. Furthermore, we established that the maximum possible data rate is mostly limited not by the relay or the mobile but by the available resource at the base station.

It is our expectation that the changing number of active mobile users in a real system will influence the results. Therefore, we examine this in our current research. Another topic for further research is considering the impact of environment parameters such as inter-cell interference.

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References

1. 3GPP TS 25.309. FDD Enhanced Uplink; Overall Description.
2. Albert Bel and Gonzalo Seco-Granados Jose Lopez Vicario. The benefits of relay selection in WiMAX networks. In *ICT-MobileSummit '08*, 2008.
3. D. C. Dimitrova, H. van den Berg, G. Heijenk, and R. Litjens. Flow-level Performance Comparison of Packet Scheduling Schemes for UMTS EUL. volume 5031. WWIC '08, Tampere, Finland, 2008.
4. A. Mäder, D. Staehle, T. Liu, and H. Barth. Feasible load regions for different RRM strategies for the enhanced uplink in UMTS networks. In *Springer, Lecture Notes in Computer Science*, volume 4396, pages 213–228. EuroNGI Workshop, 2006.
5. S. Ramakrishna and J. M. Holtzman. A scheme for throughput maximization in a dual-class CDMA system. ICUPC '97, San Diego, USA, 1997.
6. Eike Reetz, Rainer Hockmann, and Ralf Tonjes. Performance Study on Cooperative Relaying Topologies in Beyond 3G Systems. In *ICT-MobileSummit '08*, 2008.
7. C. Rosa, J. Outes, T.B. Sorensen, J. Wigard, and P.E. Mogensen. Combined time and code division scheduling for enhanced uplink packet access in WCDMA. IEEE VTC '04 (Fall), Los Angeles, USA, 2004.
8. R. Schoenen, R. Halfmann, and B.H. Walke. An FDD Multihop Cellular Network for 3GPP-LTE. pages 1990–1994, 2008.
9. Martina Umlauf. Relay Devices in UMTS Networks - effects on Application Performance. In *Proceedings of the Fifth Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net 2006)*, 2006.
10. Josep Vidal, Olga Munoz, Adrian Agustin, Eduard Calvo, and Andreu Alcon. Enhancing 802.16 networks through infrastructure-based relays. In *ICT-MobileSummit '08*, 2008.
11. E. Weiss, S. Max, O. Klein, G. Hiertz, and B. Walke. Relay-based vs. Conventional Wireless Networks: Capacity and Spectrum efficiency. pages 1–5. Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on, 2007.
12. Marc Wener, Peter Moberg, and Per Skillermark. Cost assessment of radio access network deployment with relay nodes. ICT-MobileSummit 2008 Conference Proceedings, 2008.