Performance evaluation of Cellular Networks with Mobile and Fixed Relay Station

H. Nourizadeh, S. Nourizadeh, R. Tafazolli

Centre for Communication Systems Research (CCSR)
University of Surrey, UK

***Abstract*— It is foreseen that the next generation of cellular network would integrate the relaying or multihop scheme. In a multihop cellular architecture, the users are not only able to communicate directly to the base station (BS) but can also use some relay stations to relay their data to the BS. These relay stations can either be the users' mobile station (i.e. mobile relay station) or some low cost station placed at specific location (i.e. fixed relay station). The main objective of this paper is to compare the difference between the relaying network architecture with mobile or fixed relay station as well as their performance gain. At first, the different advantages and disadvantages for each relay station method are given. Then, the capacity gains of the two methods are compared with a dynamic system level simulator. For this we integrate the relay station into conventional cellular networks using the UMTS FDD air interface. The results show that under certain conditions the uplink capacity gain of 35% is readily achievable for both form of relay station.**

***Index Terms*—Relaying, CDMA, Capacity, Mobile and Fixed Relay Station, Cellular Networks, Mesh Networks.**

I. Introduction

In a conventional cellular network, a base station (BS) controls a number of mobile station (MS) within its own coverage area and all the terminals communicate directly with the BS. However with an ever-increasing demand for mobile communications, we need to investigate new access schemes as well as novel system architectures to improve the offered cell capacities without increasing the required radio frequency spectrum. One of the main impediments to successful data transmission is error due to fading and interference. In the current conventional cellular networks, all MSs, even those far away from their BS have to communicate directly with the access point, requiring high levels of radiated powers and causing considerable interference to the neighboring cells. A possible solution is to use the concept of relaying in a cellular network. With relaying capability (also commonly known as multihop cellular network) in the cellular network the users are able to send their data directly to the BS or use some relay stations (fixed or mobile) to relay their data to the BS. In such architecture, the link is broken down into shorter paths requiring less power and hence creates less interference to the neighboring cell. With less interference, more users can be accepted in the system and the capacity is increased. In addition to capacity improvement and power saving, another important benefit is the coverage enhancement. Indeed, with the use of relaying the blind spots can be eliminated effectively and hence the coverage of the system can be enhanced. It is clear from the above discussions that multihop architecture is a promising approach to the capacity and coverage improvement of a cellular network [1]. However, there are issues that also need further investigations. One challenge is to qualify and quantify such enhancements for both capacity and coverage. In the literature two different types of relaying network architecture have been investigated. One proposed to use others users' terminal (Mobile Relay Station, MRS) to relay the traffic while others proposed to use Fixed Relay Station (FRS). The two different concepts are illustrated in Fig.1.

In this paper, we focus on the capacity gains of the relaying system with both types of relay stations (fixed and mobile).

First, [2] proposed to relay the signal through some repeaters (which are fixed station that amplify and forward the received signal) in order to improve the cell coverage. Then, [3] suggested to relay through others user's terminal (Mobile Relay Station, MRS) in order to provide more flexibility to the cellular network. Since then lots of studies have been done on the relaying system with either FRS [4], [5] or MRS [6], [7]. On the other hand very few studies have modeled and compared the two systems. Reference [8] simulated a relaying system with MRS and FRS for CDMA cellular networks. They showed the performance is not significantly improved with MRS but can be improved by 20% with FRS using Time Division Multiplexing and directional antenna. However in the model with MRS, the MS and Relay Station (RS) transmit at the same carrier frequency, which create high interference at the RS and therefore degrade the performance of the relaying system. Reference [9] defined the cellular networks architecture with MRS and with FRS. They showed that the transmission power, due to the path loss reduction with relaying, can be reduced in both cases, which can be turn into a capacity gain. However it is still not clear which concept will be more advantageous in terms of performance but also practicality.

In this paper, first the different characteristics of the MRS and the FRS are listed and discussed in section II. Then the two different relaying systems model with MRS and FRS are described in section III. And their performance evaluations are shown in section IV. A conclusion is drawn in section V.

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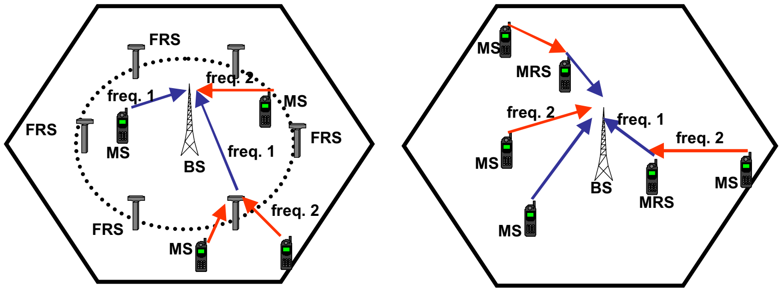

(a) with FRS (b) with MRS

Fig.1. Cellular Networks with Relaying

II. Mobile and Fixed Relay Station characteristics

A. *Relaying through Mobile Station*

In a cellular network with mobile relay station, the non-active MS (i.e. in idle state) are potential candidate to relay the traffic of the active MS to the BS. However, due to the mobility and the density of the MS, relaying with MRS brings several advantages and disadvantages (listed below) that should be considered in a realization of such a network.

1) Benefits

- The main advantage of a relaying system using MRS would be the low deployment/maintenance cost, since other user's terminals can potentially act as relays

- The MS are able to organize themselves in order to cover some unknown dead spots , which are difficult to predict with the operators planning tool [7]. They can help unpredictable events like accidents or infrequently occurring such as demonstrations or sport events**.** They can also be used where it is not cost effective to install FRS such as mountainous environment or subway train platform.

- If there are a large number of idles MS, there are more choice to select a MRS that can optimize the system performance. For example, a relayed user can choose a MRS with whom it experiences a LOS link.

- If the source terminal and the destination terminal are close to each others, they can communicate directly without sending their traffic through the BS as it is in conventional cellular networks.

2) Disadvantages

However, adding the communication capability between the users in cellular networks brings several disadvantages:

- It is obvious that the relaying opportunity depends strongly on the user's density.

- Relaying through other users terminals can considerably decrease the battery life of the mobile relay station.

- The relaying system performance is highly dependent of the RS selection scheme [10].

- The signaling (new channel MS-RS, inter-relay handover, RS selection) required for the relaying system might increase considerably.

- The cost of the terminal to support relaying (hardware and software) will increase. In addition, the implementations at the hardware become even more difficult if a MRS needs to relay more than one MS's traffic at the same time.

- Due to the mobility of the relayed MS and the MRS, frequent inter-relay handoffs might occurs, which might increase the signaling and affect the relaying system performance.

- Some others issues such as fast fading, power control or security need more investigations in order to make possible the communication between MSs.

B. *Relaying through Fixed Station*

1) Benefits

- The FRS are part of the network infrastructure, therefore their deployment will be an integral part of the network planning, design and deployment process. Hence, the operators will have a better control of the coverage and capacity expected in a specific area where the FRS is employed.

- The FRS can be deployed at strategic locations in order to maintain a LOS with the BS. They can also use directional antenna to improve the propagation link with the BS.

- The FRSs are less constrained by energy consumption. They may potentially be equipped with more advanced hardware, which enable them to operate in any frequency band as well as allow them to relay several MS at a time.

- The use of FRS eases the problem of RS selection since fewer number of FRS are deployed compared to MRS. Therefore the signaling overhead required for the RS selection will not be a major issue when relaying with FRS.

- The inter-relay handoffs will occur only when the relayed MS will move from one FRS to another FRS.

- Due to their sophisticated hardware, it is more secure to relay through a FRS than MRS. The data are always transferred through a known (fixed) RS.

2) Disadvantages

- The main disadvantage of using FRS is the infrastructure's cost. The dimensioning, planning, optimization and maintenance of the FRS can be expensive and cost inefficient. Furthermore it might be cost ineffective to install FRS if there are many sparse coverage holes, in which only a few mobile terminals are located [6].

- Since the number of FRS is limited and their locations are fixed, some MS might not be able to reach the FRS. Although, this depends on the number of FRS deployed in the system. There is a trade off between the number of FRS vs. the infrastructure cost.

C. *Discussions*

From the MRS's and FRS's characteristics listed above, it can be noticed that relaying with MRS is a more challenging network. Thus before a relaying system with MRS can be realized, many issues need to be investigated.

One of the main challenges of relaying through other user's terminals is allowing the MRS's battery to be used for someone else's call. One potential scheme to convince the user's terminals to be used as relay would be to provide them a share of the excess revenue. Another alternative solution to avoid the battery consumption of the RS would be to relay the signal through vehicles (such as cars or taxi).

Another main issue of the MRS's use is the increase of the signaling overhead. However [3] suggested using MRS only to forward the traffic to the BS and exchange the signaling directly with the BS. One may think that the additional hardware and software will increase the terminal's cost but the investigations done in [3] suggest that the required functionality for MS to support relaying has negligible impact on mobile terminal cost. In comparison to the FRS, one of the main challenges with MRS is the frequent inter-relay handoffs. This issue has been studied in [11], and the results showed that with a practical inter-relay handoffs scheme the MRS still improves the capacity of the conventional cellular network as well as limiting frequent handoffs to relay station.

III. Cellular Networks with Relaying

In order to quantify the capacity gain that relaying brings to the cellular, we compare the performance of a cellular network without and with relaying. In this section, a detailed description of the cellular networks model with MRS and FRS are given for the uplink scenario.

A. System description

For both models (without and with relaying) all the assumptions are the same for fair comparisons. For example, a predetermined number of users are uniformly distributed over the whole system. After the handover mechanism, the users select the BS with the strongest pilot signal as the serving BS. Some users are considered active, which means they transmit information on the data channel while the rest are considered to be in an idle state. In the non-relaying model, the active users transmit their data directly to their serving BS. The received Signal-to-Interference Ratio (SIR) of each active user is calculated at the BS and the number of users in outage in the system is found. A user is considered in outage if its received SIR is below the SIR target. This process is repeated for several steps. One step (or snapshot) represents one location for all users. If the received SIR is below the SIR target for a certain number of steps, the user is assumed to be unsatisfied.

In the relaying model with Fixed or Mobile RS, the active users with bad channel quality relay their data to the BS through a relay station. References [10] showed the performance is optimal when the relaying is carried out for all the MS experiencing a SIR less than the SIR target in the direct link. Therefore only the MSs in outage will relay their data through a RS. The selection of the RS depends on whether the RS is fixed or mobile and it is explained in the next sub-sections. For simplicity, a maximum of two-hop communication (one hop for the MS-RS and one hop for the RS-BS communication) is considered in the relaying model.

In this paper, the MS transmit using the UMTS FDD mode. Since a RS cannot transmit and receive at the same carrier frequency, two different carriers are needed in the relaying system. In this model, the non-relayed MSs transmit directly to the BS either with one carrier frequency (F1) or with a second carrier frequency (F2). While the RSs transmit to the BS with the frequency F1 and the relayed MS with the frequency F2 to the RS, see Fig. 1. In such scenario, the same number of MSs should transmit in both carrier frequencies (F1 and F2).

Since two carrier frequencies are used, in order to make fair comparison, the model is compared with the non-relaying system using also two carriers. There is no interference between users transmitting in different carriers but only between the users transmitting in the same carrier frequency (F1 or F2). Fig.2. depicts the interference model for two adjacent cells using relaying. In order to keep low the level of interference in the system, a perfect distributed power control is implemented. It consists of balancing all the received SIR around the SIR target. After the power control algorithm, the SIR of all the links MS-RS, RS-BS and MS-BS are calculated. For a detailed calculation of the different SIR please refer to [10]. The relayed users are considered in outage if at least one of the two hops experiences a SIR below the SIR target. Thus the percentage of unsatisfied users in the relaying system can be calculated and compared to the non relaying case.

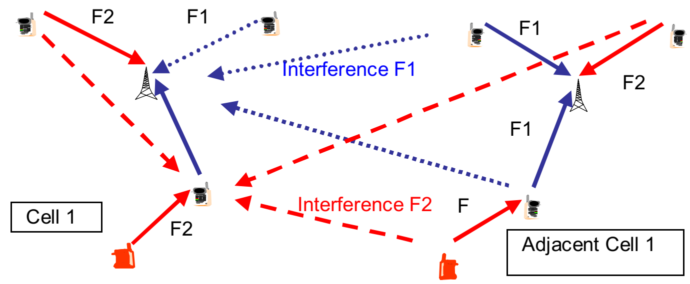

Fig.2. Interference model in a relaying system using two carriers frequencies in UMTS FDD

B. Relaying model with Mobile RS

In a cellular network with MRS, the potential candidates to relay the signals are the non-active users. Depending on the density of the non-active users, a relayed MS can select from a pool of users in idle state. However when a MS needs to be relayed, it must choose a suitable mobile relay station amongst the possible candidates. Not choosing the optimal relaying node can have great impact on the overall system capacity. Therefore different relaying MS selection schemes were proposed and evaluated in [10]. The results showed the best system performance is obtained when the non-active MS whom provide the strongest total SIR is selected as relay station. Total SIR means the sum of the SIR in the two hop links (MS-MRS and MRS-BS). In this model, we assume one MRS can relay only one MS at a time. Therefore, if two MSs want to relay with the same MS, the priority will be given to the one with the worse link quality (using path loss as criteria) with the BS. However, there are enough non-active MS placed in the system that all the MS requiring relaying are able to find a relay station. Due to the mobility of the relayed MS and the MRS's, the propagation channel condition between the relayed MS and their MRS change all the time. If the quality of the channel is getting worse, the relayed users would probably need to handover from one MRS to another MRS with better channel quality. This process, particular to the relaying system, is called the inter-relay Handoffs (IRHO). If the IRHO happen frequently, the relaying system will not be practical due to an increase in Radio Resource Control (RRC). The IRHO becomes more challenging since Mobile RS are moving conversely to the Fixed RS. The impact that the IRHO can have on the system performance with relaying is studied in details in [11]. In order to avoid frequent IRHO, the proposed scheme in [11] is also modeled.

C. Relaying model with Fixed RS

In a cellular network with FRS, a number of stations are placed at specific locations in the cell so as to relay the signal of users in outage to the BS. Since there are only a few number of FRS in a cell, the relayed MS will have few choices to select a FRS. For that reason, the FRS selection is not an issue as important as with MRS, where there are many relay candidates. In our relaying system, the relayed MS select among the two closest FRS, the one with whom it experiences the greatest SIR. It may happen that several MS select the same FRS since there are few FRS deployed. However, we have realistically assumed the FRSs are able to relay several MS at a time. As a result, the FRS will send as much as data as the number of MS that it relays. This is taken into account in the model by increasing the data rate of each FRS in function of the number of relayed MS. As a consequence, the SIR target between the FRS and the BS will increase proportionally. Since a FRS relay the data of several MS, it is very important to have a good propagation channel between FRS and BS. In our relaying model, we assume the FRS are located at lampposts in the streets where they experience a LOS with the BS.

IV. PERFORMANCE EVALUATION

A. Environment Model

The system modeled includes 19 hexagonal cells of radius 2000m, with BS at the center of the cells employing omni directional antenna. The MS follow the mobility and the propagation model as proposed in [12] for the vehicular environment. An auto-correlated shadowing is considered between the MS and the BS. In the case of relaying with MRS, there are no appropriate path loss models that describe the channel between MSs since a mobile terminal is usually positioned around head. However, the Lee model, which takes into account the receivers antenna height, is chosen as model [13]. For the relaying case with FRS, the FRS are placed at lampposts level so we use the path loss model as in [12] for the FRS-BS link and a modified path loss model for the link MS-FRS as explained in [14]. The uplink scenario with the same fixed transmission rate for voice service is applied to all the active users and the relaying model is applied to all the 19 cells. The model is simulated at system level and the simulation has been run for 1000 correlated snapshots. The simulation result is based on the percentage of non-satisfied user. A user is considered non-satisfied if its SIR is not above or equal to the SIR target - 0.5 dB for a certain period of time (the period chosen is 5 consecutive seconds [12]). At the end of the simulation, the numbers of non-satisfied users were calculated without and with relaying (MRS and FRS) for the central cell and compared.

B. Results

In this section, we compare the performance of the relaying system with the non-relaying one for different numbers of active users. The results shown for the non-relaying system represent the cellular network with two carrier frequencies used in each cell.

1) Capacity improvement with MRS

Fig.3. shows the non-satisfied users probability for the non-relaying system and the relaying system with MRS. The graph shows that the capacity is improved with relaying. For an unsatisfied users probability of 2%, the number of accepted users is 92 without relaying, while with relaying, it is almost 124, which translates to an improvement of 35%. This is due to the fact that some users can now successfully transmit their data to the BS through other users. Additionally in the non-relaying case, the users that cannot reach the BS transmit their signal with maximum power. While in the relaying case, they transmit to the MRS with lower transmit power, resulting in lower interference. Since the level of interference is lower, more users can be accepted into the system and hence the system capacity improves.

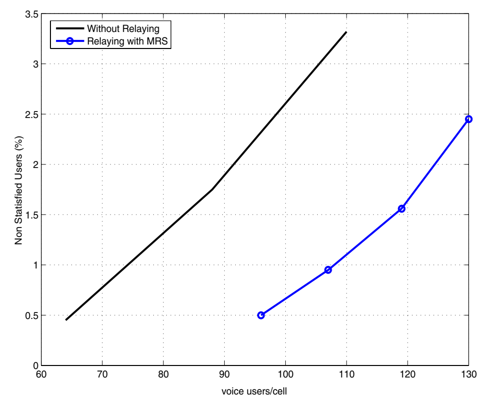

Fig.3. Performance evaluation with MRS

2) Capacity improvement with FRS

In the cellular network with FRS, six FRS per cell are placed at half of the cell's radius away from the BS. The FRS use a maximum transmit power of 24dBm while the MS's maximum transmit power is 21dBm. Fig.4. demonstrates the non-satisfied users' probability for different numbers of users per cell without and with relaying. The results showed the relaying system accepts 118 users per cell for a non-satisfied user equal to 2%. Hence the capacity of the conventional network can be improved by 28% with the use of 6 FRS.

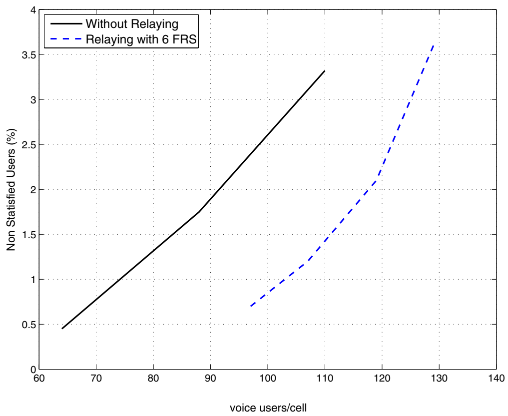

Fig.4. Performance evaluation with FRS

3) *Performance comparison MRS and FRS*

In a cellular network with MRS, the performance will depend on the density of non-active MS candidate, on the MRS selection scheme and on the IRHO mechanism. While in cellular network with FRS, the performance will essentially depend on the number and the location of the FRS. Fig.5. shows the percentage of non-satisfied users for different number of users per cell for the conventional cellular network, the relaying system with MRS and the relaying system with different number of FRS. The results show that relaying with MRS can increase the capacity by 36% for a non-satisfied user's probability of 2%. As the number of FRS increases, the performance is also improving. Greater the number of FRS is (i.e. above ten FRS per cell) and greater performance gain over MRS will be achieved.

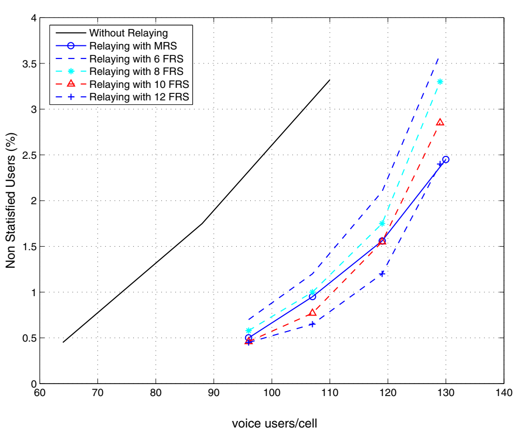

Fig.5. Performance evaluation with MRS and FRS

V. Conclusion

In this paper, we compare two relaying system architecture: one with MRS and another one with FRS. First, the advantages and disadvantages of relaying system's type (MRS or FRS) were listed and summarized. From the characteristic of the MRS, it is clear that many issues such as Mobile relay selection, signaling overhead, battery consumption, user's density or security need more investigations. The characteristics of the relaying system with FRS showed that most of the issues of existing with MRS could be solved or simplified. The simulation result showed that with more than ten FRSs the performance gain outperforms the MRS. Therefore, if and only if the deployment of the FRS is cost efficient, it is reasonable to think that relaying will be first performed through FRS. Otherwise, another alternative would be to use vehicles as relay station.

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